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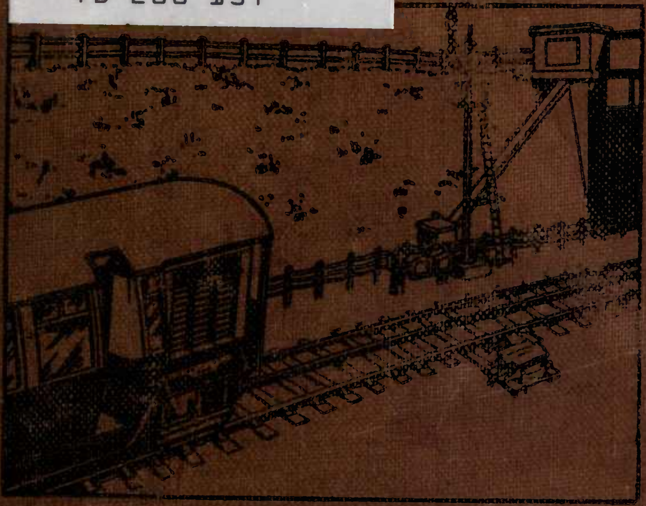

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RAILWAY SIGNALLING:
AUTOMATIC

PITMAN'S TECHNICAL PRIMER SERIES
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RAILWAY-SIGNALLING: AUTOMATIC

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RAILWAY-SIGNALLING: AUTOMATIC

AN INTRODUCTORY TREATMENT OF THE PURPOSES, EQUIPMENT, AND METHODS OF AUTOMATIC SIGNALLING AND TRACK-CIRCUITS FOR STEAM AND ELECTRIC RAILWAYS

FOR RAILWAYMEN, STUDENTS, AND OTHERS

BY

FRAS. RAYNAR WILSON

ASSISTANT ENGINEER, VICTORIAN GOVERNMENT RAILWAYS

PITMAN'S TECHNICAL PRIMERS

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FOREWORD

I COULD not, as I looked through the accompanying pages of my son's book, help allowing my thoughts to wander over the changes that have been made, in my day, in railway-signalling. When I entered the railway service five-and-forty years ago, signalling, generally, was very primitive. Now it is almost perfect ; the machine itself has reached perfection, but the man behind the machine is human and, therefore, frail. It is in this latter respect that there is any weakness, and therein lies the main cause for the demand for automatic signalling and track-circuit—the subject of the present work.

I remembered, too, that, although this perfection has now been reached, its development has been slow. It might have been reached much earlier, because, in 1872—four years before I joined the railway—Sykes put down his first automatic signalling at the Victoria Station of the Metropolitan District Railway and Dr. Robinson patented his method of track-circuit on which all the automatic signalling of to-day is based.

It is within the last twenty years that there has been this great development. At the time my first book was published, in May, 1900, there was no automatic signalling in this country, except that, since removed, on the Liverpool Overhead ; there were not half-a-dozen installations of track-circuit, and only one power signalling plant, and that in a goods yard.

Some five or six years later all these features—automatic signalling, track-circuit, and power signalling—became an acknowledged success in this country owing to their adoption and use throughout the Metropolitan District Railway when it was converted to electric traction and on the Tube railways of London. Whilst this mainly may have been brought about by the adoption of American methods, credit is due to English railway officers for having appreciated the advantages to be gained and, although the United States may have set us the example, it is safe to say that our installations are more complete.

The following pages relate more particularly to automatic signalling and track-circuit. Both these lead to greater safety and to closer working of trains —each productive of economy. For both there is a wide field and, as a consequence, there is a need for literature on the subject. Such literature is worse than useless unless it be authoritative and understandable. For that and other reasons, I have read through these pages with care, and feel that I may safely commend them as giving that class of information and guidance which a student of the subject needs.

Having myself written more than any other man on the art of signalling, I have been anxious that my son's efforts should be successful. I desired also that this work should take a good place among the excellent technical primers of Messrs. Sir Isaac Pitman & Sons, Limited. I feel satisfied that the accompanying work meets these conditions, and that I may commend it with confidence and with no little paternal pride.

H. RAYNAR WILSON.

PREFACE

AUTOMATIC railway-signalling has made great progress during the last few years, is constantly being improved upon, and is certain to be largely extended in the near future in order to increase the carrying capacity of existing lines—incidentally thereby often postponing the duplication of tracks ; to eliminate the human agent and thus reduce the possibilities of accidents ; on new railways, and on lines not now fully signalled, in preference to providing signal-boxes and a staff of signalmen ; in substitution of existing signal-boxes and manually-operated signals in order to reduce expense. The United States lead the way in the number of miles protected by automatic block signals, having 38,544 miles so equipped at the end of 1920. In Great Britain, Canada, and Australia, much progress is being made ; and in the near future other Colonies and Dependencies will have installations in service.

This small volume is intended to give some particulars of the different methods adopted by railways and signal firms to provide safe and efficient automatic signalling. In a subject so highly technical and with conditions so diversified, it is impossible to describe, within the space available, all the methods usable to meet similar conditions, or to enter into a lengthy description of each piece of apparatus. Instances have been taken which, in the Author's opinion, are typical of the different phases of automatic signalling. Should the reader desire to extend his knowledge on the subject, the bibliography at the end will be found useful.

An endeavour has been made to show how the different methods may be applied, after a brief outline of typical apparatus used. A fair working knowledge of electricity is assumed, and therefore no explanation of electrical matters is attempted ; on the other hand, no previous knowledge of automatic signalling is assumed, and elementary principles are dealt with before leading to the latest developments.

The Author wishes to thank Mr. F. M. Calcutt, Engineer of Signals, Victorian Railways, for permission to use departmental photographs and drawings ; and the following signal engineering firms for photographs and certain blocks illustrating their respective apparatus : Messrs. The Westinghouse Brake and Saxby Signal Co., Ltd. ; the British Power Railway Signal Co., Ltd. ; the W.R. Sykes Interlocking Signal Co., Ltd ; and the General Railway Signal Co. Finally, as, owing to his absence from England, he is unable to see the pages through the press, the Author has to thank his father, Mr. H. Raynar Wilson, for kindly undertaking this task.

F. R. W.

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ILLUSTRATIONS

SYMBOLS AND ABBREVIATIONS

THE following symbols and abbreviations, adopted by the International Electrotechnical Commission, are used in this volume—

V = volt	mA = milliampere
A = ampere	kVA = kilovolt-ampere

RAILWAY-SIGNALLING: AUTOMATIC

CHAPTER I

PURPOSES AND ADVANTAGES OF AUTOMATIC SIGNALS

One of the reasons why British railways have not installed automatic signals to the same extent as the railways of North America is to be found in the fact that the former were already fully mechanically signalled and manually operated, and different devices and appliances were in use for the safe working of trains, before a commercial use could be made of automatic signalling. In comparison with the very high standard which had been reached by British railways as long ago as the early "eighties," little signalling of any kind had been done in the United States. Coincident with the realization, by American railway officers, of the fact that signalling saved delays and accidents—thereby saving money—came the introduction of the track-circuit and the automatic signal. Automatic signalling was, therefore, adopted in preference to signal-boxes, mechanically-operated signals, and their attendant signalmen. As these signals secure the space interval between trains given by the block system, the provision of the latter was avoided. Except at junctions and in busy stations, the points were not concentrated and interlocked as was the British practice; but this was, in part, met by the track-circuit for the automatic signals having switches on the points so that the signals could not clear if the points were open.

By the time that efficient and reliable apparatus had been designed, manufactured, and tested by actual service conditions, it required more than merely re-signalling a section to recommend the adoption of automatic signalling to British managers, especially those conservative traffic officers of the old school who pinned their faith to the methods they had introduced, nursed, and had seen grow. These had no faith in automatic working and preferred the human element. They argued, for instance, that an automatic signal could not detect a hot axle-box or the shifted load on a wagon. For these small weaknesses—which are trifles when gauged by the greater safety in other directions that automatic signalling brings—no progress was made in automatic signalling in England until the beginning of the present century. On the other hand, it must be confessed that the few railway accidents that occur on British railways prove that the existing methods in service are quite safe and sound ; and given the adoption of track-circuits to provide a check on the signalman's operations, a wholesale replacement of the existing arrangements by automatic signalling may not come for some years yet.

Primary Action of Automatic Signalling. The primary action of automatic signalling is that the passage of a train actuates and controls the signals, without the aid of any individual, and provides the protection of trains from following ones. At junctions, crossovers, public road level crossings, and such interlocking places, it is necessary for someone to control the movements of trains, but between two such places the signals can work automatically by the use of track-circuits.

In large station yards interlockings are so close together that automatic signals could not be installed, the control of the train being in the hands of the signalmen all the time, whether the interlockings are mechanically or power operated, especially where movements of points are being made continuously day and night.

Elimination of Intermediate Signal Boxes. Where intermediate signal-boxes are used merely for block working purposes, the provision of automatic signals makes these boxes unnecessary, and so saves money by the elimination of signalmen's wages and maintenance charges for the signal-box, apparatus, stores, etc. With the increased wages now ruling, this would amount to a considerable sum per annum; and as the automatic signal works 24 hours per day and 365 days per annum at a low-power consumption, the savings effected by closing one signal-box will pay the interest on a capital sum invested to install a fair length of automatic signals. Regardless of these savings, there is the feature that automatic signals not only work day and night and on Sundays, but do not fall asleep on duty nor go on strike.

Switching-out of Signal-boxes. Another factor is the facility by which a signal-box, that is only required to be worked once or twice a day, may be switched out at other times, and the signals controlled from the lever frame may then work as automatics, provided the signal levers are in the reverse position. With such boxes, it is not always necessary for a fully-qualified signalman to make the required operations when the frame is required to be used, as one of the station staff can be given the required training and authority. Switching-out of signal-boxes working on the existing block telegraph systems is done at night and on Sundays, but in this case the distance between the outer block stations is greatly increased, with a consequent longer space interval, and thus a less number of trains per hour can travel over the section.

By converting the running signals into semi-automatic, i.e. signal-box operated at times and automatically operated at other times, the existing block sections (and, therefore, the same number of trains) remain and the trains are protected as safely as with the block system—probably, owing to track-circuit being necessary, more so. The only disadvantage is that a man must go into the box should a train have a vehicle to attach or detach.

Elasticity of Automatic Signal Spacing. As is described in another volume of this series,* the spacing and location of manually-operated signals controlled from a signal-box are guided by certain conditions, whilst the placing of the signal-box itself is determined by traffic requirements, i.e. the situation and number of stations, junctions, sidings, public road level crossings, etc. Again, if the trains are numerous and the number of boxes at stations, junctions, etc., is less in proportion, intermediate signal-boxes have to be provided. Thus the more trains required to travel over a line, the less should be the distance between the signal-boxes. Automatic signals, on the other hand, can be located so as to suit traffic requirements and to give the maximum efficiency of train operation. The time spent in sending the different code rings on the block instruments between the boxes is a factor against quick working, and this operation is saved with automatic signals. The space between two automatic signals should never be less than service-braking distance, i.e. sufficient distance for a train to be brought to a stand by the normal application of the brakes, when a driver passes a signal that warns him to be prepared to stop at the next signal.

Automatic Train Control. With many systems that have been installed, and especially on rapid transit railways, the additional use of automatic train control has been provided, which gives a further safeguard at a very little increased cost. This is a mechanical check on the driver obeying the signal when a " stop " or " danger " signal indication is displayed, for should he pass or over-run a " stop " indication, special apparatus on the locomotive or

* *Railway-Signalling: Mechanical,* by Fras. Raynar Wilson. (Pitman, 2s. 6d. net.)

train comes into contact with a device fitted on the track and controlled by the signalling system, thereby applying the brakes. Different such systems are described later in this book.

Financial Considerations. The cost of installing automatic signalling depends a great deal on the source of power employed. When battery signals are used, it is found that the first cost is comparatively low, but the maintenance charges are high. Where either direct current or alternating current power is obtainable, the provision of transformers, cables, etc., requires a higher capital charge, but the maintenance charges are greatly reduced.

It should be noted that whilst the cost of installing automatic signals may be known, the actual saving by such an installation can never be ascertained accurately. The saving of signalmen's wages is determined easily, but it is impossible to state the monetary equivalent of such improvements as the more equable running of trains, the safer conditions under which the trains are operated, and the greater capacity of the tracks, which postpones the need for duplicating them.

Reliability of Automatic Signalling. The design and manufacture of automatic and power signal apparatus have reached such a high standard of perfection, that the number of signal failures due to defective design is negligible, and, indeed, the number of signal failures from all causes is very small in comparison with the number of movements made. Dangerous or "false clear" failures are very rare. At the same time, although such a high standard has been reached, signal engineers and signal manufacturing firms are constantly investigating the latest branches of science and engineering to provide the most approved signalling. The maintenance of this type of apparatus calls for a more highly trained man than is required for the ordinary mechanical signalling. In addition to a knowledge of mechanical work, he must have a fair knowledge of electrical engineering, especially when dealing with alternating-current signalling.

CHAPTER II

TRACK-CIRCUITS FOR STEAM RAILWAYS

As the track-circuit is the fundamental and principal basis on which the automatic and power-operated signal has been developed, it will be as well to give a brief description of the arrangements and methods used on both steam and electric railways before dealing with the different systems of signalling. The principle of the track-circuit is the same for all railways, but steam railway methods will be described first, as in the majority of cases these are operated by track-circuits fed from batteries, and have not the more complicated arrangements necessary for electric railways. At the same time, it should be understood that to reduce operating costs it is preferable to use direct or alternating-current generated power* on steam railways, if such power be easily obtained ; and, therefore, such power may be utilized for feeding the track-circuits in addition to being used for operating the signal mechanisms. Under these circumstances, the track-circuit apparatus is not so complicated as on electric railways. In this chapter, therefore, the only difference between the battery and generated power track-circuit is in the source of power and the relays, other items being practically identical ; although it is not possible, in the space available, to describe all the different methods that have been adopted.

Normally-closed Track-circuit. This type of track-circuit is illustrated diagrammatically in Fig. 1.

* I.e. power derived from dynamo-electric generators instead of from primary batteries.

The positive terminal of the battery is connected to one set of rails. The rails are electrically connected to each other by wire bonds, and the current flows along one set of rails in the direction shown by the arrows to the relay, passing through its coils and returning along the other set of rails to the negative pole of the battery. Insulating rail joints are placed at each end of the section, thus isolating one section from the adjacent sections. In some cases, only one side of the running rails is provided with insulating

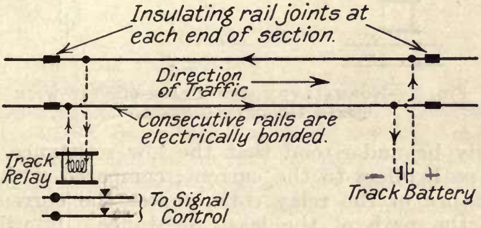

FIG. 1.—SIMPLE TRACK-CIRCUIT. NORMALLY CLOSED TYPE.

joints, the other side being continuous—this arrangement constituting a "single rail track-circuit"—but this is not advisable, as it does not provide for broken rail protection as fully as the "double rail track-circuit," in which both sides are insulated. The single rail track-circuit, however, has to be adopted at interlockings in many cases, and in all cases where interlockings occur on electric railways. The type of circuit shown in Fig. 1 is termed a "normally-closed" track-circuit, because the relay is normally energized and closed, unless a vehicle or train is occupying the track.

Fig. 2 shows the effect of a train occupying the section. The return path is now through the pair, or pairs, of wheels of the train, and consequently there is little or no current flowing through the relay coils. The relay is, therefore, de-energized, and any circuit taken through the relay contacts is thereby broken. The wheels and axles of the train must, of course, form a metallic circuit for this to be done, otherwise, as in the case of the Mansell wheel, it is necessary to bond the wheels to the axle. It will

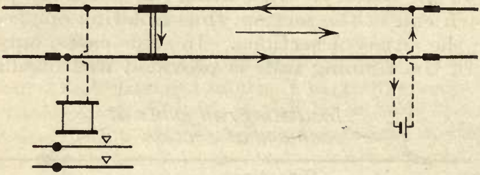

FIG. 2.—NORMALLY-CLOSED TRACK-CIRCUIT WITH TRAIN OCCUPYING SECTION.

readily be understood that the low resistance that this path offers to the current, compared with the resistance of the relay coils, causes the current to take the path of the least resistance. It will be noticed that the relay is placed at the entrance of the section ; this is done because the shunting of the relay is effected more efficiently by this arrangement.

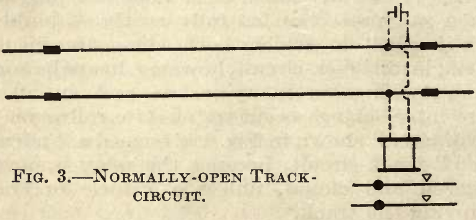

FIG. 3.—NORMALLY-OPEN TRACK-CIRCUIT.

Normally-open Track-circuit. In a few cases, a normally-open track-circuit is used, the connections being as shown in Fig. 3. In this case, the circuit to the relay is closed only when a train is occupying the track. This was the original form of track-circuit, but the arrangement is fundamentally faulty for automatic signal practice, and should never be used for this purpose. It is sometimes used in connection with an indicator giving warning that a train is approaching a signal, although such arrangements are now being superseded by the closed track-circuit.

Track-circuit Components. From the above it will be seen that four units are required for a complete track-circuit—

(1) Source of power.
(2) Bonding of the rails.
(3) Insulating rail joints.
(4) Track relay.

Source of Power for Track-circuits. The track-circuit should be supplied with as low an e.m.f. as is practicable, and the current capacity of the battery should not be excessively great, nor yet too limited. Low e.m.f. is required in order to minimize the "break down" effect of the voltage upon damp or defective insulating rail joints and other parts that afford a normal leakage of current from rail to rail in wet weather; also, to reduce to a minimum the energy normally discharged from the battery through the sleepers, ballast, and relay when the track section is unoccupied, and to avoid extravagant discharge when the section is occupied by the train. Leakage across the insulating rail joints is termed "end-leakage," and a certain amount of current leaks from rail to rail by means of the sleepers and ballast; this has to be taken into account when calculating track-circuit values. Fig. 4 is a diagram showing some of the leakages and resistances in the track-circuit.

The more usual battery consists of two cells connected in parallel, but sometimes a series-parallel arrangement is made. It is customary to arrange for the polarities of each single or double rail track-circuit to be opposite to that of the adjoining track-circuit ; otherwise, should an insulating joint become defective, it is possible for a relay to be energized from the adjoining battery when a train is occupying the track. During the time the track is occupied, the battery is short-circuited, and this may cause an excessive discharge and an extravagant consumption of energy, with consequent high maintenance charges for renewals. With the " gravity " cell, there is sufficient internal resistance in the cell itself to combat this effect ; but where current supply is taken from caustic soda cells, storage batteries, or a dynamo, an external resistance is required. This

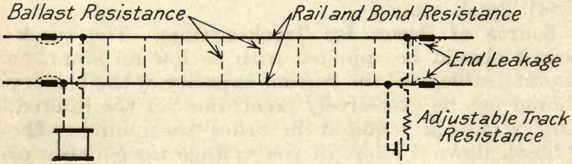

FIG. 4.—RESISTANCES AND LEAKAGE PATHS IN TRACK-CIRCUITS.

is put in series with the feed from the battery, as shown in Fig. 4. If alternating current be used, either a resistance or some form of impedance is necessary.

As the internal resistance of a battery is variable, the use of cells having a high internal resistance is not advisable, and it is preferable to use a cell having a low resistance and to provide an external adjustable resistance, which may be varied to suit the current requirements of any particular track section. The caustic soda cell does not require renewing as often as the gravity cell, and is rapidly coming into favour for track-circuiting purposes.

The efficient operation of the track-circuit is dependent on so many varying conditions that it is necessary to have as many of these as possible adjusted and graduated, thus reducing the unknown values to a minimum. The effect of the weather is one instance of the variations which occur, as in wet weather there is more leakage across rails through the roadbed than during dry weather. The resistance of the leakage path between rails varies with the nature of the ballast, the condition of the sleepers, and weather conditions. In order to reduce the leakage as much as possible, the ballast should always be kept free from touching the rails. It has been found that the resistance of the sleepers and ballast per 1,000 ft. of track is as follows: Wet gravel, 3 ohms; dry gravel, 6 ohms; wet broken stone, 6 ohms; dry broken stone, 16 ohms. In actual practice, it is usually found that the resistance of the ballast is 8 ohms per 1,000 ft. when dry, 5 ohms when damp, and 2 ohms when wet.

Another factor influencing the working of track-circuits is the length of the latter; the length varies considerably with circumstances, but the variation is not great where the signals are used under similar conditions. In the space here available, it is not possible to give formulae for calculating track-circuit values, but reference may usefully be made to certain causes which may militate against the efficient working of the circuit.

Although the track-circuit seems a simple kind of circuit, it is the one item in signalling in which signal engineers are not too satisfied that perfection has been reached, and concerning which there is found a diversity of opinion as to the best practice. The different conditions under which the circuit has to work make the theoretical survey vastly interesting, but very complicated. Contrary to usual electrical operation, the battery or generator is under maximum load when no apparent useful work is being done, as the current output is highest when the relay is de-energized.

Excessive sanding of the rails might prevent the track current flowing through the wheels, the relay then remaining energized with a train in the section. The same result might be obtained where the traffic is infrequent and the rails have become rusty, also when vehicles are light in weight. These latter conditions rarely occur where automatic signals are used, but are occasionally met at interlockings where the sidings are used on rare occasions and portions of the sidings are in the fouling zone of the main line. It is under such circumstances that the track-circuit must be proved as being an efficient safeguard for the protection of trains.

Bonding of Rails. Although the fish-plates used for connecting the rails together provide a metallic path for an electric current, the small voltage employed on track-circuits and the high resistance that would occur were a number of the fish-plates rusty make it necessary for some better means of conductivity to be provided. This is done by bonding the rails together by No. 8 S.W.G. galvanized iron wire; No. 6 B. & S. (8 S.W.G.) copper-clad steel wire; or copper wire, stranded or solid. On electric railways where the running rails are used for propulsion return purposes, high conductivity bonds are installed to carry the power current across the rail joints; the track-circuit current then flows through the same bonds, and no further provision is necessary.

The holes for the bond heads are drilled into the rail by special drilling machines, which enable the holes to be made quickly. When holes have to be drilled in rails at points and crossings where such a machine could not be employed, use has to be made of a ratchet drill and clamp.

It has been proved that when rails are new and joint bolts are tight, nearly all the current flows from rail to rail through the fish-plates; but when the rails have been worn, a coating of rust and dirt forms between the rail and fish-plate, forcing practically all the current through the bond wires. The bonds should be connected to the rails when the rail is freshly drilled, so as to make a good electrical connection. The resistance of rails and bonding per 1,000 ft. of track should not exceed 0·15 ohm when ordinary bonding is used. The figure for electric railways is usually about 0·0104 ohm per 1,000 ft.

Usually two bonds are fixed. One type of bond is shown at *A* (Fig. 5), which consists of two copper

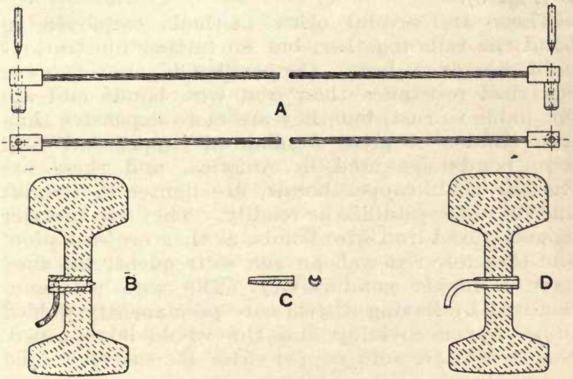

Fig. 5.—Illustrating Construction and Application of Rail Bond.

terminals, S.W.G. connected by a stranded wire 19/21 or 19/24 S.W.G. soldered into holes drilled in the heads of the terminals, the whole being tinned over. The portion of the terminal to be fitted in the rail is drilled with a hole of varying diameters, so that the terminal will be expanded into close contact with the rail when the steel drift pin is driven in, as shown at *B* (Fig. 5). As the rectangular head of the terminal lays flat against the web of the rail, no special tool is required to drive in the drift pin.

When No. 8 galvanized iron wire is used as a bond, a channelled pin is employed to fix it in the rail. The pin, *C* (Fig. 5), which is tapered, is made of steel, and has a longitudinal channel on one side to fit over the bond wire. The bond wire is first placed in the hole in the rail, the channelled pin is placed over the end of the wire on the opposite side, and then driven in, the taper of the pin ensuring a close contact between the wire and the rail as shown at *D* (Fig. 5).

There are several other methods employed to bond the rails together, but no further illustrations need be given here. Copper bonds are of lower electrical resistance than iron wire bonds and are not liable to rust, but they are more expensive than iron bonds. A great number of copper-clad steel wire bonds are used in America, and these are cheaper than copper bonds, are lighter in weight, and do not crystallize as readily. They are superior to galvanized iron wire bonds, as they are rust proof and therefore renewals are not so frequent, and they have a higher conductivity. The wire is manufactured by having a steel core permanently welded to a copper covering and the whole is annealed. No. 8 S.W.G. soft copper wire is used for solid copper bonds.

When bonds are in service, constant attention should be given to detect any broken wires, and these should be renewed as early as possible. Particular attention must be paid, when the direct current propulsion return is taken through the running rails, to prevent unbalancing of track-circuits as described in the next chapter. Under these circumstances, it is desirable for the signal, and not the permanent-way, department to be responsible for the maintenance of the bonding. In addition to ordinary examination, electrical tests should be made by one of the several methods adopted by different railways.

Insulating Rail Joints. There are several good types of insulating rail joints in service. To give efficient service, these joints should be so designed that they can easily be taken to pieces and be put back again without much trouble. One cannot see from the outside of the joint whether the insulating plates and bushes are in good condition ; and, although methods are in use whereby the joints can be tested electrically, periodical inspection and investigation should be made. Probably many of those failures, for which no cause is found, are due to defective insulation of rail joints, and the passing of a train temporarily clears the fault. The permanent-way department is generally responsible for the actual maintenance of these joints, the plate-layers doing what is required.

Before the insulating joint is fixed, the rail ends should be free from any burrs and rough edges which may cut into the insulation, and the rails and joints should have all rust, scale, and other foreign matter removed before fixing. The casting should be so placed that the bolts may easily be inserted ; under no circumstances, should the bolts be driven home, as this might damage the insulating bushes. Care should be taken that the bolts are kept tight ; any looseness of the joint soon breaks down the insulation. Attention should be given to rail-creep, as the rails may cut through the fibre plate and bonds may be broken from this cause. The joints should be kept clean, as metal dust may bridge the track-circuits and cause a failure. The attention of the permanent-way men should be drawn to any insulating joint which is not properly supported, as this tends to loosen the joint.

A distinctive type of insulating joint is made by the W. R. Sykes Interlocking Signal Co., Ltd., which has three patterns in service. Fig. 6 shows the ordinary pattern made either in cast or stamped steel. The illustration shows the method by which the joint is fixed to the rail with a fibre plate inserted between

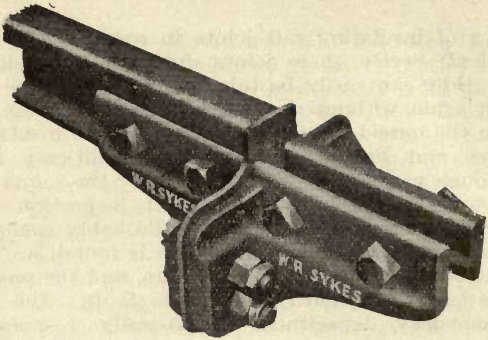

FIG. 6.—SYKES' INSULATING JOINT FOR ORDINARY RUNNING RAIL.

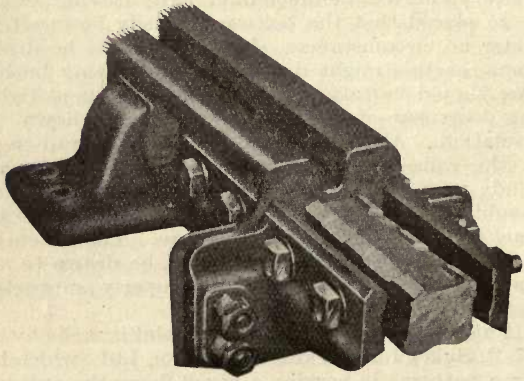

FIG. 7.—FILLER-UP INSULATING JOINT FOR CHECK RAIL.

the rail ends. Fibre bushings and washers are used for the bolts connecting the two halves of the joint. Fig. 7 shows the pattern used for check rails, made up with two ordinary insulated joints, and two cast-iron blocks or fillers acting as distance pieces between the rails ; this type of joint requires the removal of one rail when it is installed. An alternative joint, which can be fixed without disturbing the rails, is shown in Fig. 8. This consists of two ordinary

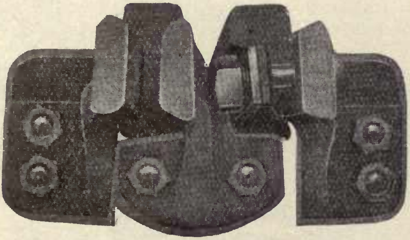

Fig. 8.—Check Rail Insulating Joint which can be Fixed without Interfering with Rails.

joints and one special joint fixed between the rails, as seen in the illustration.

Another type of joint, manufactured by the Westinghouse Brake and Saxby Signal Co., Ltd., is shown in Fig. 9. This consists of four steel channel plates, two on each side of the rail, a fibre plate insulating these plates and the ends of the rails. Moulded fibre pieces are fitted between the channel plates and the continuous fish-plates. The holes in the outer fish-plates are bushed with fibre, and fibre washers are placed between the fish-plates and the steel bolt washers.

Fibre is the insulation generally employed in this service, and it has given every satisfaction. When it is remembered that the fibre plates are sometimes watersoaked, baked in hot sunlight, and frozen in winter, and, at all times, are under strains caused by the passage of trains and the expansion and contraction of the rails, it will be realized that it is necessary for the material to be of the best quality possible. The fibre should be of a horny nature, made from paper containing only cotton or linen rags, and should have no water-repelling substance applied to its surface. It must be free from chlorides

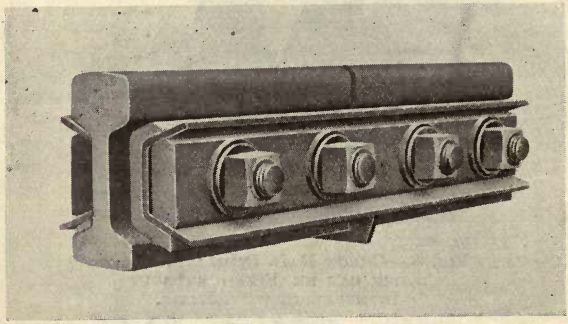

FIG. 9.—W. B. & S. S. CO'S. INSULATING JOINT FOR ORDINARY RUNNING RAIL.

and glycerines, as well as from chemicals that will in any way tend to shorten its life or lower its insulating qualities under any condition of service. It must be capable of being bent into a circle of a radius of ten times its thickness, without cracking or splitting. When bent to the point of rupture, it should break off square and not split.

Track Relays. The track relay, which is the " king pin " of the automatic signal, varies in shape and design according to the manufacturer's patents. The relays are fitted with contact fingers as required, through which the circuits for the signal and other controls are taken. The ends of these contact fingers are connected to terminal posts by insulated flexible conductors.

As the relay has to be operated by such a small current under such varying conditions, many experiments have been made with different resistances of

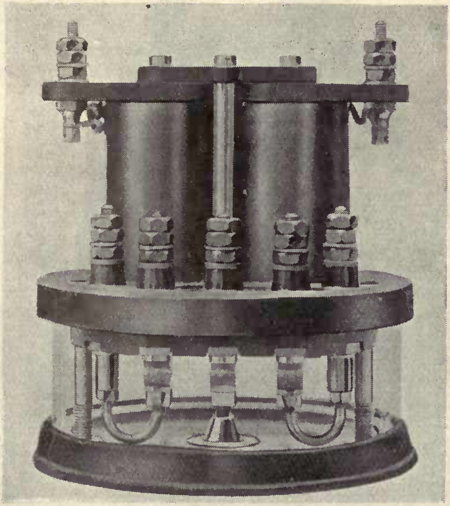

FIG. 10.—SYX D.C. TRACK RELAY.

relay coils for different lengths of track. Probably in Great Britain the majority of relays are of 9 ohms. In the United States, the use of 4-ohm relays is almost universal; but, of recent years, a number of 2-ohm relays have been installed for trial.

Fig. 10 illustrates the standard track relay manufactured by the W. R. Sykes Interlocking Signal Co., Ltd. In general, it follows the build of what has come to be known as the American-type relay, but it is constructed on novel lines. The whole of the top part is contained in a one-piece moulding made of insulating material, an arrangement which ensures much higher insulation qualities than the ordinary

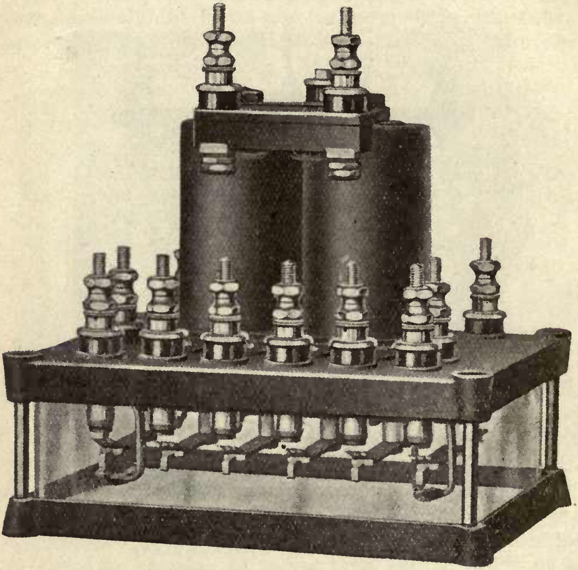

FIG. 11.—TRACK RELAY FOR SHELF MOUNTING.

plan in which a number of insulating collets and bushes have to be used. An improved transportation screw is fitted, which can be used at any time, if the relay has to be sent on a journey, after it has first been put to work. Three front and two back contacts are supplied, and these can be made of various materials to suit engineers' wishes. The small number of parts in its construction makes this relay a very satisfactory one in service.

Another type of relay is shown in Fig. 11. This is manufactured by the British Power Railway Signal Co., Ltd., and is made for fitting on a shelf.

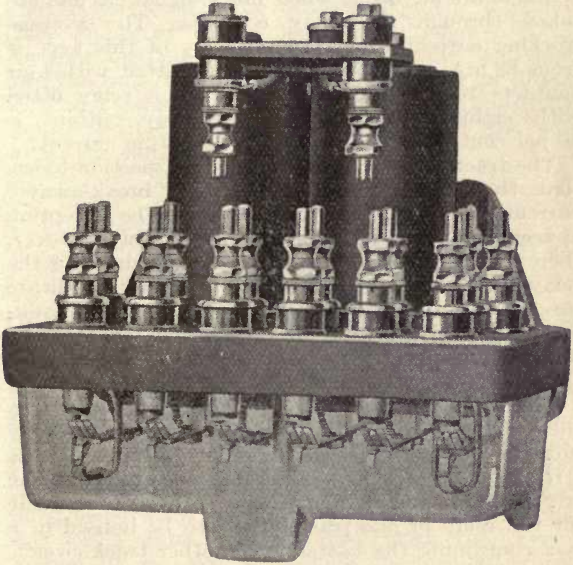

FIG. 12.—TRACK RELAY FOR WALL MOUNTING.

It is constructed by the coils being wound on a horseshoe magnet, and the armature is fitted with from two front and back contacts to two front and back and four independent front contacts, as shown in the illustration. Another form of this relay, shown in Fig. 12, is made for fitting on to a wall. The contact points give a rubbing movement when either making or breaking contact, and this is essential with all signalling relays. Platinum to graphite for front contacts, and platinum to platinum for back contacts, are usually supplied, although, if required, platinum to silver-plated graphite, or copper to graphite contacts are made. The latter contacts are advisable when 110 V signal circuits are taken through the relay contacts. The average working currents for a 4-ohm relay of this type is from 83 mA and 0·33 V for a relay fitted with four contacts to 115 mA and 0·46 V for a relay fitted with eight contacts. The drop-away current is 40 per cent below the minimum operating current.

The track relay requires frequent inspection to see that the correct " pick-up " and " break-away " currents are being maintained. With the exception of seeing that the terminals are kept tight, however, there should not be much attention required for the relay itself, as these instruments, although of delicate mechanism and calibration, are very well manufactured. Adjustments are generally external to the relay, and should the armature require re-adjustment, this should be made in a suitably equipped shop.

The relays are generally housed near to the tracks they "detect," as long leads from the track to the relay increase the resistance in the circuit and may cause a relay not to pick up. The same rule applies to the battery end, and in many cases provision is made for the relay of one track-circuit to be housed in a box containing the battery of another track-circuit. It is advisable to reduce the resistance of the leads as much as possible, and any long leads that are necessary should be compensated for by adjusting the external variable resistance at the battery end of the track-circuit. The Signal Section of the American Railway Association specifies that the resistance of the leads from battery to track should not exceed 0·15 ohm, and leads from relay to track not to exceed 0·10 ohm. Resistance of relay contacts under most adverse conditions should not exceed 0·2 ohm.

Connections from the relay or battery on to the rails are made by several methods. One method is to prepare pigtails of insulated wire, on which is sweated a lug suitably drilled. A rivet is placed through the hole in the lug and the hole in the rail, and then riveted. The other end of the pigtail is then connected to the leads by a sweated joint. Another method is for an iron wire to be riveted into the rail, the track lead being twisted on to this wire and sweated. In some cases, an additional copper flexible wire is sweated from the iron wire on to the rail.

CHAPTER III

TRACK-CIRCUITS FOR ELECTRIC RAILWAYS

On electric railways using direct current for propulsion, two methods are used to provide for the return of the propulsion current to the generator. One of these methods is to use a fourth rail as a negative contact rail, as on the London Underground Electric Railways and the Metropolitan Railway. The other method is to return the current through the running rails, as on the Central London Railway and the Great Western Railway extension between Shepherd's Bush and Ealing. With the former method, it is easy to provide the insulating rail sections necessary for signalling purposes, and by using polarized relays for the track it is possible to prevent any undue interference with the direct current track-circuit by any foreign direct current leakage.

When the running rails are required to carry d.c. or a.c. propulsion return, it is obviously impossible to insulate the track-circuits from each other and at the same time provide a continuous path for the propulsion return, unless by some special arrangement. Simultaneously with the facing of this problem came the introduction of an alternating current operated track relay developed by Mr. J. B. Struble, of the Union Switch and Signal Co., and later by the invention of a balanced impedance bond. The latter piece of apparatus is also employed when alternating current propulsion is used, but the frequency of the signalling power is made different from that of the traction power.

D.C. Track-circuits on D.C. Railways using Fourth-rail Return. The principal railway system using this method is the London Underground Electric Railways, where electro-pneumatic signalling has now been in service for some years (*see* Chapter V). The principal British manufacturer of this signalling system is the Westinghouse Brake and Saxby Signal Co., Ltd. This firm is the maker of the Brown polarized track relay described below, which was first developed for operation on the Boston Elevated Railway.

On the Metropolitan District Railway, the d.c. signalling main is maintained at a pressure of 60 V, and the positive side of the signalling generator is earthed to prevent interference from the propulsion current. A feed is taken from the negative main through a high-resistance tube, which reduces the voltage to between 2 V and 6 V for feeding the track-circuit, and this is connected to one side of the running rails, as shown in Fig. 13. As will be seen from the diagram, one of the running rails is continuous throughout the line. This is connected to the positive side of the generator, and used as a common return for the signalling current. The other side of the running rails has insulating block joints fixed, and it is to this side that the track feed is taken. Two Brown polarized relays are used for each track-circuit—one, *A*, at the entering end and

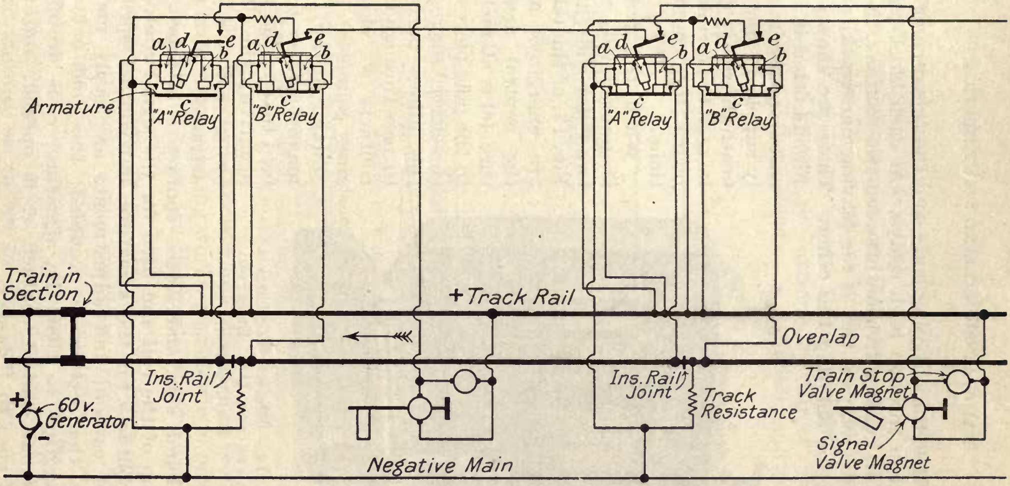

FIG. 13.—D.C. TRACK-CIRCUIT ON D.C. ELECTRIC RAILWAY.

one, *B*, at the outgoing end—and the signal controls are taken through both relays. At each block-joint location, i.e. the division between two sections, there are two relays: the *B* for leaving one track, and the *A* for entering the other. These are shown in Fig. 14 fitted in the cast-iron case usually supplied; underneath the relays can be seen the terminal board for connections.

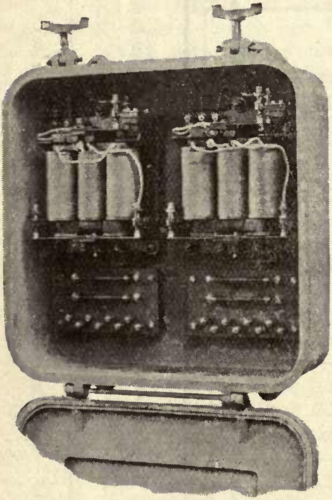

FIG. 14.—BROWN POLARIZED RELAYS FOR D.C. ELECTRIC RAILWAYS.

When the track is unoccupied, the two outer coils, *a*, *b*, Fig. 13, of the relay are energized and the neutral armature (*c*) is attracted to the pole pieces of the electro magnet; this allows current to pass through two contacts so closed and connects the centre polarized magnet, *d*, on to a feed taken from the negative main. The swing coil, *d*, is attracted to the right-hand side and closes contact *e* attached to the top of the coil and used for the signal controls. The contacts for the armature and contact springs are of carbon, and adjustments are easily made. When the section is occupied, the coils *a b* are de-energized so that the armature, *c*, is dropped, the signal control contact, *e*, is opened, and the signal goes to "danger."

The resistance tubes are usually fixed in a separate housing near the relay case.

A.C. Track-circuits on D.C. and A.C. Railways. Alternating current track-circuits and signalling are largely in operation now. Being immune from the dangerous effects of extraneous direct current, capable of selection between signalling and traction

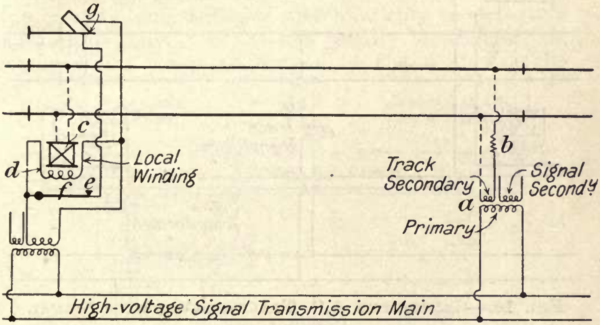

FIG. 15.—END-FED A.C. TRACK-CIRCUIT WITH SIGNAL CONTROL.

(*a*) Secondary winding of transformer; supplies current to track rails.
(*b*) Resistance, or reactance to prevent a large flow of current from *a* when the rails of two adjoining sections are joined together by a train.
(*c*) Track winding of relay, energized from the track rails.
(*d*) Local winding of relay, energizes from local transformer.
When *c* and *d* are both energized, the relay brings the contact finger on to the contact *e*, and so closes the circuit to signal *g*.

alternating-current power, and giving more economical operation by reducing working costs where power can be obtained, they are gradually superseding other systems.

The principle of these track-circuits is similar to that described in the previous chapter. The a.c. signalling main voltage is stepped down by transformers to the required working pressure for the track-circuits. In the majority of cases, the tracks are end-fed as shown in Fig. 15; but sometimes when the section is very long, it is centre-fed, as in Fig. 16, in which case a track relay is required at each end. In the signalling systems described later, details are given of the track transformers used ; in this chapter the track relays, impedance bonds, and reactances are described.

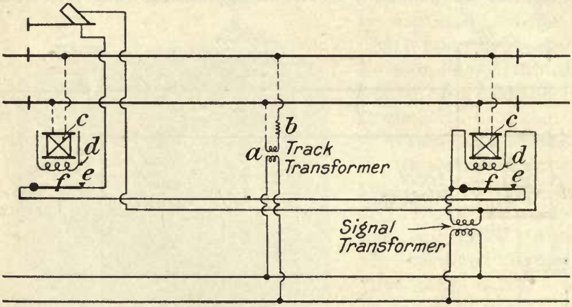

FIG. 16.—CENTRE-FED A.C. TRACK-CIRCUIT WITH SIGNAL CONTROL.

Impedance Bonds for D.C. Railways. The impedance bond is required to provide a continuous path for the return of the propulsion current, when the two running rails are insulated into sections for signalling purposes. By the use of these bonds, the amount of signal power required for the operation of the track-circuits is increased, because a path between the two track rails is provided through the impedance bonds, in addition to the normal path through the relay and ballast. The bonds are placed at the end of each track-circuit, and are connected as in Fig. 17, which shows the direction of the different currents.

Before a suitable bond can be chosen or designed, it is necessary to know what current each running rail is to carry for the traction system. This depends upon the distance the substations are from each other, the number and weight of the trains, and the rating of their motors. These are matters for the operating and electric traction departments to decide ; the signal department is concerned only with the current to be carried by the rails.

The next factor is the allowable impedance of the bond, and the percentage variation of this impedance due to unbalanced direct current owing to defective bonding of rails, etc. As will readily be understood, should a few bonds be broken on the *A* side of the

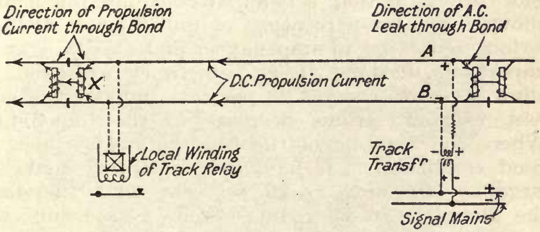

FIG. 17.—DIAGRAM ILLUSTRATING FLOW OF PROPULSION (D.C.) AND SIGNALLING (A.C.) CURRENTS THROUGH IMPEDANCE BONDS.

running rails in Fig. 17, the higher resistance along this length of rails will cause the return current to flow along the *B* side, and thus cause an unbalancing at *X*.

An impedance bond consist of a laminated iron core about which, but insulated therefrom, are wound a few turns of heavy copper bar or cable. Two windings are provided, wound in opposite directions and so connected to the running rails that the magnetizing action of the direct current return in one-half of the winding is opposite to that of the other half of the winding. With the same number of turns in each winding and an equal amperage flowing from each rail, the magnetizing forces are equal, and consequently there is no magnetic flux in the iron core. If, however, there is more direct current flowing in one rail than in the other, due to a higher resistance in the latter caused by defective or broken rail bonds, there is a resultant flux in the iron core, tending to saturate it, lowering its permeability, and consequently decreasing the impedance of the bond to the alternating current of the track-circuit. This result is termed " unbalancing," and to reduce this effect an air gap is made in the iron core. A bond with an air gap will allow more signalling current to leak through it than a bond without one, but it also allows a greater percentage of unbalancing without serious reduction of impedance, and this is a more important matter. It is sometimes arranged to allow bonds to carry a 20 per cent unbalancing current without serious decrease in the impedance. Where the bonding of the running rails is kept in good condition, it is hardly necessary to make so large an allowance as 20 per cent, and, therefore, the air gap can be reduced and, as a result, the leakage current through the bonds.

The ohmic resistance of the bond to the direct-current return is very small—in some cases as low as 0·0004 ohm between the rail and the neutral point on each half of the bond—but the impedance to the track-circuit current is necessarily high, as this current tends to flow from A to B (Fig. 17), and were it not for the choking effect of the bond, a short-circuit would ensue. Under ordinary circumstances, a certain amount of track current does flow through the impedance bond from A to B, but not sufficient to shunt the relay.

In Fig. 18 is shown an impedance bond used on the Victorian Railways and manufactured by the General Railway Signal Co. ; the dismantled components are shown in Fig. 19. These bonds are designed to take 1,000 A from each rail, the two connections to each rail being sweated into the lugs

*L*1 and *L*2, which are in turn bolted on to the coil at *C*1 and *C*2. The four connecting cables (each of 0·25 sq. in. cross section) used between the centre points of the adjacent bonds for the neutral connector are sweated into the lug *L*3, which is bolted to the strap *S*, and the strap is bolted on to the coil at *C*3. The terminal *L*4 is used for cross bonding between two or more tracks when this is necessary

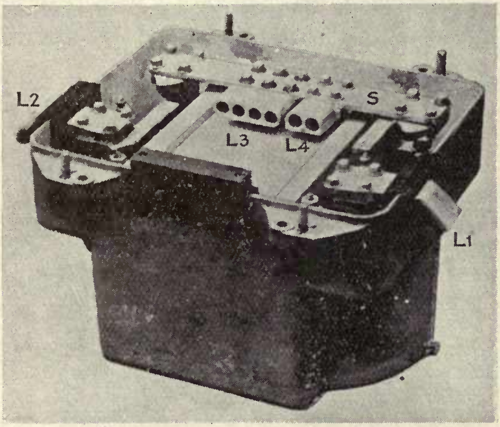

FIG. 18.—IMPEDANCE BOND WITH COVER REMOVED.

and required by the traction department. On *C*1 and *C*2 can be seen small terminals to which are connected the track-circuit leads. Fig. 20 shows these bonds, with the covers in place, installed on the track, with the connections made to the rails and leads taken from the bond to the track-circuit apparatus. The neutral connection is shown covered by wood trunking. It should be noted, to correct any misapprehension as to the size of the bond, that the rail gauge is 5 ft. 3 in.

It is the usual practice to enclose the core and coils in an iron case and to fill the case with petrolatum, a vaseline compound which insulates and protects the windings from moisture. Being a

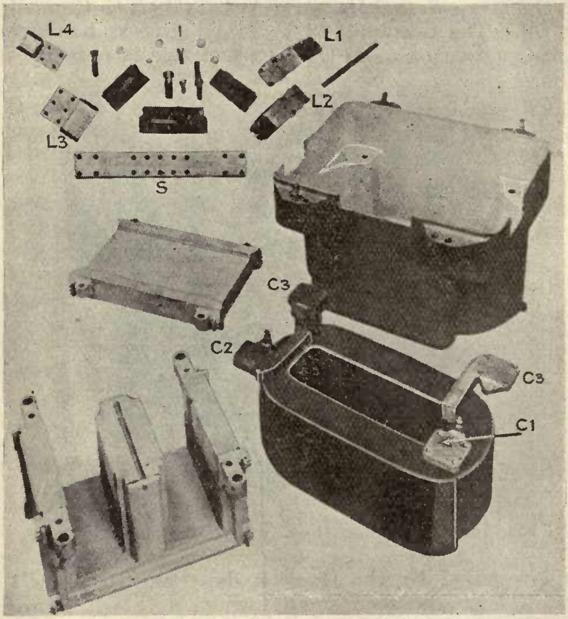

FIG. 19.—DISMANTLED COMPONENTS OF IMPEDANCE BOND.

solid, it cannot be forced out like oil should the bond become flooded with water. Petrolatum should be a pure mineral oil, free from acid alkali and other injurious chemicals. The bonds described require 35 lbs. of petrolatum in each case.

Fig. 21 shows an impedance bond by the

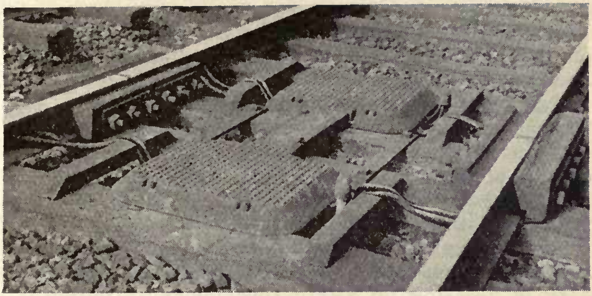

FIG. 20.—IMPEDANCE BONDS INSTALLED ON TRACK.
Victorian Railways; rail gauge 5 ft. 3 in.

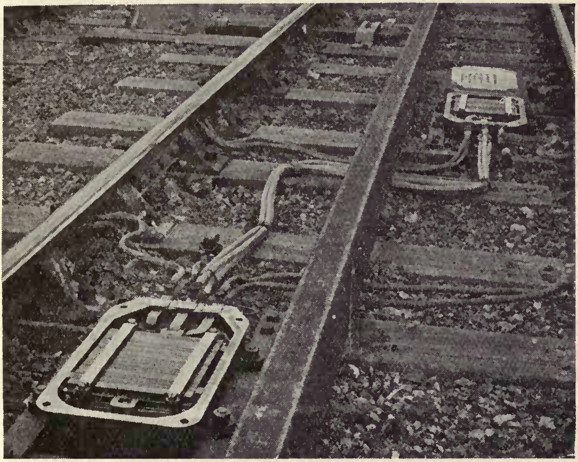

FIG. 21.—IMPEDANCE BONDS INSTALLED ON TRACK.
Great Western Railway extension, between Shepherd's Bush and Ealing.

Westinghouse Brake and Saxby Signal Co. installed on the G.W.R. extension between Shepherd's Bush and Ealing.

Resonated Impedance Bonds. As already explained, the necessity of providing for unbalanced propulsion current requires the use of an air gap in the iron circuit of an impedance bond, thus considerably increasing the magnetic reluctance and lowering the impedance of the bond to alternating current. A considerable amount of alternating current may then flow through the bond and, as this current is engaged only in creating an alternating magnetic flux, the current is not in phase with, but lags considerably behind, the voltage applied to the bond terminals. It is well known to electrical engineers that, in any alternating current circuit, a leading current may be used to neutralize a lagging current in such a manner as to reduce the current which has to be supplied to the circuit to a small amount which is in phase with the applied voltage. This form of circuit is generally known as a resonant circuit.*

A type of bond in which the principle of resonance is used has been designed and patented by the Westinghouse Brake and Saxby Signal Co. It is somewhat similar to the type previously described, having heavy copper bars wound round an iron core, but an additional winding on the core is connected to the terminals of a condenser. Adjustments can be made to increase or lower the amount of leading current passing through the condenser. The condenser is usually protected by two low-voltage vacuum arresters, operating at about 240 V. These provide a safeguard against any excessive voltage, which might otherwise be applied to the condenser, due to sudden surges of propulsion current or other causes.

* The principles governing the neutralization of lagging currents are dealt with at length in *Power Factor Correction* by A. E. Clayton, uniform with this volume. (Pitman, 2s. 6d. net.)

The impedance of these bonds is very much higher than that of the usual type. The actual impedance obtained varies with the frequency, air gap, etc. ; but at 25 cycles per sec., with an air gap of 0·06 in., an impedance of 0·75 ohm at 0·25 V, and impedances of over 1 ohm at 1 V and upwards are easily obtained.

Tappings are provided on the condenser coils to facilitate correct adjustment for different voltages and so that the bond may be adjusted to provide a leading current to compensate for the relay and rail inductance. This type of bond is in use on several British railways.

Impedance Bonds for A.C. Railways. The impedance bonds used on a.c. railways are smaller than those used on d.c. railways, but the same principle of magnetic balancing is employed. As the voltages employed on railways operated by alternating current are much higher than on d.c. railways, the propulsion currents are lower, thus reducing the size of the bond required. Unbalancing is rarely met with on railways using alternating-current for traction, because the half winding that is carrying the heavier current induces a voltage in the other half and tends to pull a larger current through the weaker half, thus equalizing the forces and maintaining the balance of the bond. Under these circumstances, no air gap is required in the magnetic circuit to prevent saturation of the core.

Alternating-current Track Relays. Alternating-current track relays in practically all recently installed work have been of the two-element type ; i.e. having two separate and distinct windings : one, a line or track element connected to the track ; and the other, a local element connected permanently to the signalling transformer. The track element generally operates with a voltage of 1 V or less, and the local element at 110 V or in some cases 50 to 55 V. By this means it is possible to operate long track-circuits with very much less current than would be required for single-element relays. The local element or winding of two-element relays is constantly energized and, when the track is unoccupied, current is flowing into the track elements. The two elements must both be energized before the relay will operate.

Track relays generally operate in two positions ; but, as will be seen in the descriptions of three-position signalling (p. 95), relays can be operated to give three positions. Several types of relays are used : the galvanometer, polyphase, and two-element vane being the most important. Single-element vane track relays are often used for short track-circuits. The centrifugal frequency relay and the vane frequency relay are sometimes used on a.c. propulsion roads.

Ironless Galvanometer Relay. This type of relay is shown in Fig. 22 as manufactured by the Westinghouse Brake and Saxby Signal Co. As will be seen from the illustration, the essential parts are the local coils, which are constantly energized, and the armature or track element swinging in the centre of the local coils. The armature consist of a comparatively few turns of heavy wire formed and then clamped to, but insulated from, a swinging frame attached to the armature shaft. On the left-hand end of this shaft is a connecting link which actuates a pivoted bar carrying the contact fingers. On the right-hand end of the shaft are two flexible copper spirals, the inner ends of which are connected to the armature coil, the outer ends being connected to the terminal binding posts fitted on the cast-iron top plate. These are used for the track current. The feed for the local coils is taken from similar terminals on the left of the top plate directly to the coils. Small adjustable counterweight nuts are provided for balancing on each side of the armature swing-frame. Stop screws prevent the armature from striking the local coils.

The electrical principle on which this relay operates

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is as follows. The local coils are so connected that when current flows through them, magnetic fields of the same instantaneous direction are created. The fields produced in the upper and lower halves of these coils are opposite in direction. When a current is passing through the armature conductors in one

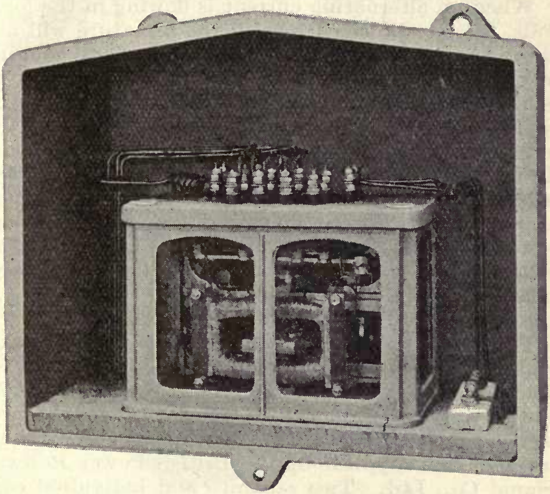


FIG. 22.—IRONLESS GALVANOMETER RELAY, WITH COVER REMOVED.

direction attraction takes place between the top of the field coil and the armature conductors and at the same time repulsion takes place between the bottom of the field coil and the armature. On the other side of the armature the reverse is the case, the lower half attracting and the upper repelling. All the time current is flowing in the armature there is a continuous torque tending to turn the armature. When the track is occupied, current ceases to flow in the armature and, as no torque is then excited, the armature drops, due to the effect of gravity, and the contacts are opened. By changing the direction of the current in the armature and suitably balancing the latter, it is possible to use these relays for three-position working.

When an alternating current is flowing in the local coils, foreign direct current in the armature will not cause the relay to operate, as the constant polarity of the armature, due to the d.c. flowing through it, is not subject to any resultant attraction by the rapidly reversing alternating magnetic field of the local coils. The relay is consequently immune from direct current and is especially adapted for railways using d.c. propulsion. The relay operates most economically when the local and track elements are exactly in phase, or 180 deg. out of phase with each other. In this respect it is different from the polyphase relay, which operates best when the currents in the two elements are 90 deg. out of phase.

Polyphase Relay. This type of relay is generally looked upon as being the most economical relay for track-circuit work, although more expensive than the galvanometer relay. These relays are of the two-element type, and Fig. 23 shows the general arrangement of one supplied by the British Power Railway Signal Co., Ltd. Two separate and individual coils are wound on the same laminated iron core, this portion being termed the stator. Inside this core is fitted a hollow metal drum without any windings and free to rotate when motion is produced, this portion being termed the rotor. The rotor is pivoted at both ends and provided with a rotor shaft ; on the end of the latter is a small pinion engaging with a segmental gear in the lower portion of the relay. This gear operates a shaft carrying the contact fingers. A counterweight is attached to the shaft, so that the segmental gear will drop by gravity when the relay is de-energized, and the contacts are thereby opened.

The electrical principle on which the relay operates is similar to that of the induction motor. One winding on the core is constantly energized from the signalling transformer, and the other is connected to the track. When both elements are charged, currents are induced in the rotor, which set up a field reacting on the field of the local coils in such a manner as to cause the rotor to turn in the direction

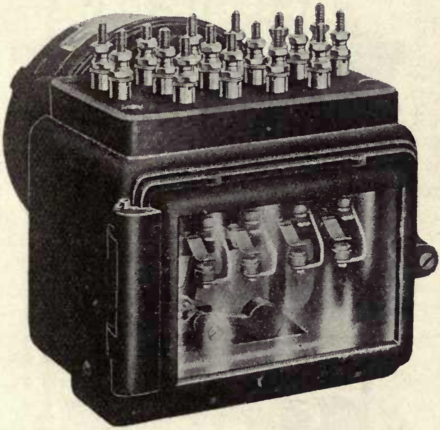


FIG. 23.—FOUR-WAY POLYPHASE RELAY.

required. To do this, it is necessary for the two currents in the fields to be 90 deg. out of phase. Thus, if the line-winding current leads the local current by 90 deg., the rotor will turn, say, in a clockwise direction; if it lags 90 deg. behind the local current, it will move in a counter-clockwise direction. If, however, the two currents are in phase, the relay will not operate; this being the reverse working of the galvanometer relay, which will only operate when the currents in the two elements are in phase or 180 deg. out of phase.

Single-element Vane Relay. The single-element vane relay was the first a.c. track relay used for signalling purposes. A relay of this type as manufactured by the Westinghouse Brake and Saxby

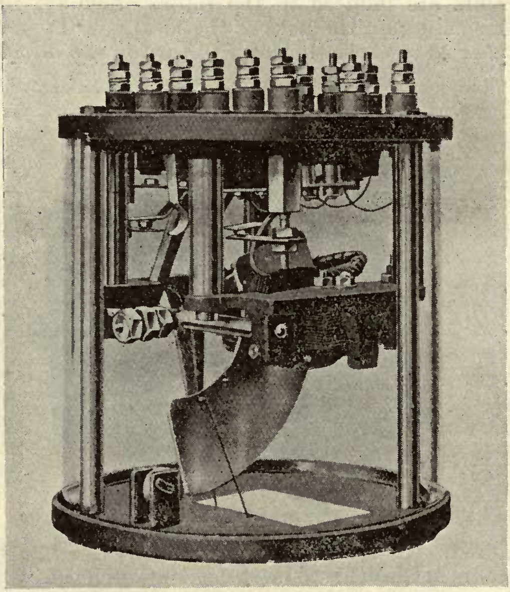


FIG. 24.—SINGLE-ELEMENT VANE RELAY.

Signal Co., Ltd., is shown in Fig. 24. The prime mover is an aluminium vane pivoted and moving vertically between the poles of a *C*-shaped laminated magnet core (*see* Fig. 26). The vane actuates a contact spring bar and, when the relay is de-energized, the vane drops by gravity on to a small fibre roller seen at the bottom of the case, Fig. 24. This roller moves uphill against gravity when struck by the vane, and thus brings the latter to rest without jar or rebound ; a similar action occurs at the end of the upward movement.

The relay depends on electro-magnetic induction. The sector-shaped vane is mounted so that it can rotate between the poles of an electro-magnet, which is supplied with alternating current. Each pole of the electro-magnet has fitted to it a " shading band," i.e. a heavy band of copper which encloses a portion only of the pole face.

The principle on which the relay operates can best be understood by supposing that two rings of copper or aluminium of the same size are suspended parallel to, and nearly in contact with, each other in the field of an alternating-current magnet. The currents induced in the rings by the alternating magnetic field will be nearly in phase with each other, the rings being nearly in the same region of the field, so that there will be attraction between them, since conductors conveying current flowing in the same direction attract each other. If the rings be displaced relative to each other as in Fig. 25 in a direction parallel to their planes (the shaded portion representing the pole of an a.c. magnet), the attraction between the rings will then tend to pull them into coincidence.

In the vane relay, one of the rings is fixed into the pole face of the alternating-current magnet and is the " shading band " ; the other ring is a portion of the aluminium vane, and this is free to rotate.

The currents induced in the shading band by the main field give rise to a magnetic field in opposition to it, causing the main magnetic flux to shift towards the " unshaded " portion of the pole face (outside the shading band). This main flux induces an eddy current in the vane at that particular point, and this, because it is induced by the main field, is in phase with the current induced by the same field in the shading band. There is thus attraction between the shading band and that portion of the vane in which the current is induced, causing the vane to move in an upward direction, or from the " unshaded " to the " shaded " portion of the pole face (*see* Fig. 26).

The movement of the vane is continuous until it is stopped mechanically, because as new portions of the vane are brought opposite to the unshaded portion of the pole, new eddy currents will be created therein,

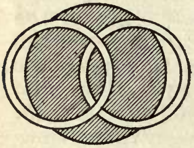


FIG. 25.—TWO RINGS IN FRONT OF A.C. MAGNET POLE.

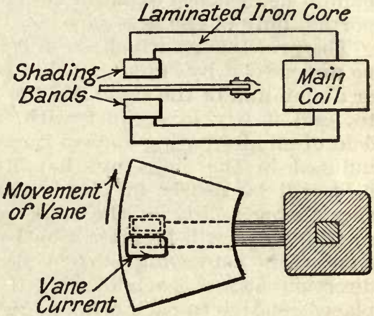


FIG. 26.—ILLUSTRATING ACTION OF SINGLE-ELEMENT VANE RELAY.

and these, in turn, will be attracted by the shading band. The movement of the vane, by a simple link, causes the contact shaft on which the contacts are mounted to be moved so as to close the contacts of the relay.

The mechanical clearances between all fixed and moving parts of the relay are large ; only a small portion of the vane is enclosed by the pole faces and, as the large air gap is vertical, there is little possibility of the vane sticking to the field structure because of foreign particles falling in the air gap. All the parts, especially the air gap, are open to easy inspection through the glass shield, without taking the relay apart.

Two-element Vane Relay. With long tracks with impedance bonds or having a low ballast resistance, the energy required to operate the single-element vane relay or the galvanometer relay is high, and the two-element vane relay was designed to overcome this difficulty. Owing to the principles on which its action depends, it is impossible to operate this relay with direct current under any condition. The main portion of the power required to operate the relay is supplied from a local source, so that the power required from the track is very small, with the result that long tracks under bad conditions can be track-circuited successfully with the aid of this relay, without any undue expenditure of energy, and maintaining at the same time a high shunt value. The moving parts are simple and free from any form of gearing, and the clearances are large, so that there is no possibility of the relay " sticking up."

The general appearance of the complete relay as made by the Westinghouse Brake and Saxby Signal Co., Ltd., is shown in Fig. 27. There are two local iron cores, one each side of the vane, and one track core which has a pole on each side of the vane at its outer radius. The local and track iron cores are fixed at right angles to one another. A vertical slot is formed by the two local cores, and in this the vane is placed (*see* Fig. 28), so that all the local flux passes twice through the vane but in opposite directions. The result of this flux cutting the aluminium conductors formed by the slots in the vane is that currents are induced in the vane and are compelled to travel along the paths between the slots as shown by the dotted lines in Fig. 29. The currents therefore pass in a horizontal direction between the poles of the track core and lag 90 deg. behind the local flux or 180 deg. behind the " local " voltage.

When a current is passed through the track

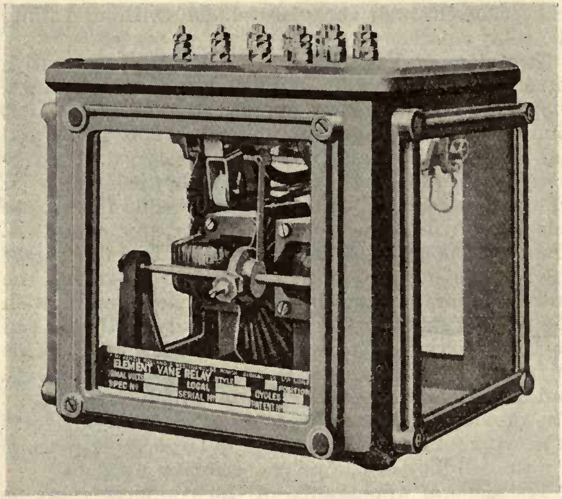


FIG. 27.—TWO-POSITION, TWO-ELEMENT VANE RELAY.

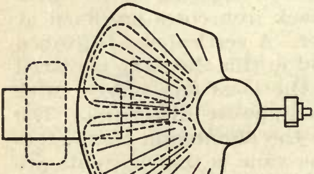


FIG. 28.—LOCAL IRON CIRCUIT IN TWO-ELEMENT VANE RELAY.

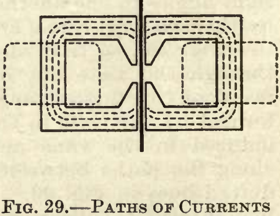


FIG. 29.—PATHS OF CURRENTS INDUCED IN VANE BY LOCAL FIELD OF TWO-ELEMENT VANE RELAY.

winding, it induces a flux across the vane which produces a force on the conductors of the vane at right angles to the direction of the currents. This tends to move the vane in a vertical direction, either upwards or downwards according to the direction of the currents in the track winding relative to the local current. The track current should be, as nearly as possible, in quadrature (90 deg. out of phase) with the local current, if the most efficient operation of the relay is to be obtained.

Centrifugal Frequency Relay. It is the practice to use a much higher frequency for the signalling current than for the traction current. In America, the usual frequency of the former is 60 cycles, and for the latter 25 cycles per sec. This has been found to give a suitable differentiation. The relays have, therefore, to be designed so as to be immune from any foreign direct current that may be picked up, and so as to be capable of selecting between the 25-cycle and the 60-cycle currents, closing the relay contacts only with the latter power.

The Union Switch and Signal Co. has two types of relays giving this service: the centrifugal and the vane frequency relays. The former is operated on the same principle as the polyphase relay (p. 38), and has a metal shell rotor working inside a wire-wound stator composed of two elements. Connected to the rotor is a Y-shaped metal yoke (*see* Fig. 30), to which are attached the ball centrifuges and the contact finger fittings. The centrifuge arms and collar work in the same way as the ball governor of a steam engine. The speed of the rotor on the 60-cycle signalling current is much higher than on the 25-cycle current, and the centrifuge arms fly out to an extent which brings the contact fingers up to the contact posts only when the 60-cycle current is flowing in the stator. Should any 25-cycle current enter the coils of the stator, the rotor will certainly rotate, but not so quickly; the centrifuge arms will not extend to any appreciable distance, and the contacts will not be closed. The relay is thus immune from operation by the a.c. propulsion power.

To prevent any sluggish movement in opening the relay contacts, due to the momentum of the rotor moving on ball bearings, a braking arrangement is necessary. This is provided by a magnetic brake shown on the right-hand side of the sketch, consisting of a coil operating an armature to which a brake pad is attached. This pad engages with a disc on the rotor when the track is occupied. The coil of

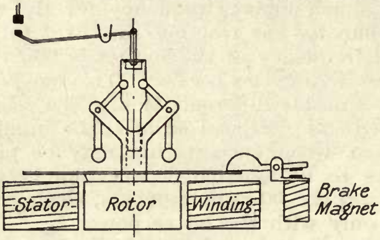


Fig. 30.—Operating Mechanism of Centrifugal Frequency Relay.

the magnetic brake is connected in series with the track-element winding, and when the track is unoccupied, the full operating current flows through this circuit and lifts the brake pad from the disc. Immediately a train enters the section, the current ceases to flow through the track winding and the brake coil ; the armature falls away ; and the brake pad engages with the disc, causing the rotor to stop and opening the relay contacts in about $\frac{1}{4}$ sec. after the track-circuit is shunted.

A number of centrifugal frequency relays have been installed for track-circuit work in England. On account of its safety and power economy, this type of relay has generally superseded the vane frequency relay, which is now mostly used for point detection purposes on a.c. operated roads, and is, therefore, outside the scope of this book. Briefly, the principle of this type of relay is the same as that of the single-element vane relay (p. 40), but the vane is constructed differently, and the windings are wound on a laminated H-shaped iron core, with a larger air gap at one end of the core than at the other. By this arrangement, it is possible to balance the torque effect of the vane when 25-cycle current is flowing through the winding ; but the balance is destroyed when 60-cycle signalling current flows, and the vane then moves in an upward direction and so closes the relay contacts. Being a single-element relay, it is not so economical in power consumption as is the centrifugal frequency relay and, for this reason, it is not used for track-circuit work.

Resistances, Impedances, and Reactances for Track-circuits. In order to prevent excessive current from flowing through the secondary winding of the transformer when a train is standing on a track-circuit and thereby shunting the latter, a current-limiting device is inserted in series with the track secondary winding and the rail. Such a device may be a resistance coil, impedance coil, or thermal regulators. These devices also supply the means by which the necessary phase relations between current and voltage are obtained for two-element track relays.

Track resistance tubes consist of a few turns of coarse wire, wound on an insulating asbestos or porcelain tube ; they are practically non-inductive, and, consequently, do not alter the phase relation of the current to the voltage.

Track impedances consist of a coil of wire wound round a laminated iron core ; they are highly inductive, and cause the track current to lag considerably behind the voltage. They are so constructed that a wide range of impedance values may be obtained.

Thermal regulators are a patented manufacture of the Westinghouse Brake and Saxby Signal Co., Ltd.

They consist of a metal filament, having a high temperature co-efficient of resistance, which is enclosed in a gas-filled glass tube with metal ends for insertion into spring contact clips. The regulators are made of various resistances, and are inserted in series with the track secondary winding of the track transformer and the rail to suit the working of each track-circuit. With any increase of current, due to the track-circuit being short-circuited, the temperature of the regulator rises and a consequent increase of resistance results, thus compensating automatically for the loss of the outside resistance of the circuit, and keeping the current output practically constant. Thermal regulators are fitted into clips supported on a base, one method being shown in Fig. 47 (p. 75).

When only one rail is used for the propulsion return, impedance bonds are not required. With automatic signals, however, double-rail track-circuits are generally employed, as one rail is not sufficient to carry the heavy propulsion return without excessive drop. At junctions, etc., it is necessary to provide a continuous path for this return, but the installation of impedance bonds would be difficult owing to the complicated track layouts. As the length of single-rail propulsion return at such places does not seriously interfere with the propulsion drop, single-rail track-circuits are permissible ; but, to prevent interference to the a.c. track-circuits from the d.c. propulsion return, shielding reactances and impedances are connected in series with the track winding of the relay and the rail, and these serve to exclude from the relay coils any direct current of sufficient magnitude to cause saturation of the magnetic circuit of the relay.

Fig. 31 shows the connections of the two windings of a polyphase track relay when double-rail track-circuits are in service ; and Fig. 32 shows the connections of the relay windings and the shielding reactance when single-rail track-circuits are used. The resistance between terminals 1 and 2, and between 2 and 3, is 0·67 ohm, and the impedance between terminals 2 and 3 is 10·6 ohms. Should

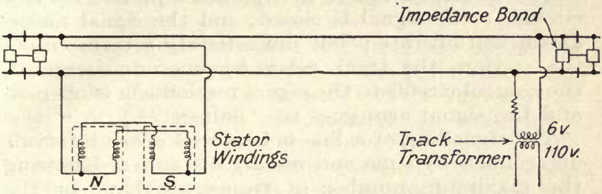


FIG. 31.—TRACK CONNECTIONS FOR POLYPHASE TRACK RELAY FOR DOUBLE-RAIL TRACK-CIRCUIT.

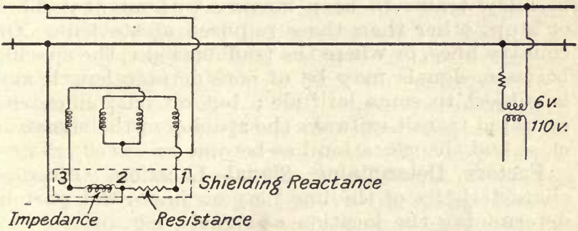


FIG. 32.—TRACK CONNECTIONS FOR POLYPHASE TRACK RELAY FOR SINGLE-RAIL TRACK-CIRCUIT.

direct current pass into the windings, a parallel path is provided, but the alternating current will flow from 2 to 1 on account of the impedance between 2 and 3.

CHAPTER IV

LOCATING AND SPACING AUTOMATIC SIGNALS

UNDER any system of signalling it is necessary for the line to be divided into sections for signalling purposes, a signal being provided at the entrance of each section so as to indicate whether the section is occupied or unoccupied by a train. With automatic signals, the track-circuit is the means by which the control of the signal is effected ; when the track relays are picked up, the control circuit to the signal is closed, and the signal mechanism will operate ; but immediately a train enters the section, the track relay becomes de-energized, the control circuit to the signal mechanism is opened, and the signal arm goes to "danger."

The signalling of a line is based on space intervals determined by time and not by distance. Knowing the maximum number of trains per hour or the shortest time interval between trains passing over the line, it is possible to signal a length of line so as to allow trains to keep moving without any check or stop, other than those required at stations. On country lines, or where the traffic is light, the spacing between signals may be of considerable length and is subject to some latitude ; but on busy lines and on rapid transit railways the spacing of the signals is close and their location has become an exact science.

Factors Determining Signal Location. Physical characteristics of the line play an important part in determining the location of signals, e.g. on a rising gradient a closer spacing of signals is possible, owing to the greater braking effect on such a grade. Also where speed is necessarily low owing to the curvature of track, the train can be pulled up more quickly than when being run on the normal speed. Conversely, on a down gradient it is necessary to make provision for the higher speed and consequent lesser braking efficiency and, therefore, to give a greater spacing between signals.

To ensure safety of operation, it is necessary that a train shall always be protected by a stop signal at such a distance behind it as would enable a following train to be brought to a stand, before colliding with the first train, by the emergency or full application of the brake should the following train (when travelling at the maximum permissible speed) pass the signal at the " danger " indication. Under any circumstances, signals should never be spaced at less than the service or gradual braking distance between signals.

In order that the signal engineer may know the acceleration and deceleration of the trains using the line, it is necessary to prepare curves showing the results of acceleration and deceleration tests taken on the trains when travelling on a level grade. The acceleration rates for steam passenger locomotives are from 0·2 to 0·5 m.p.h. per sec., and for electric motor cars on city or rapid transit railways from 1·5 to 2·0 m.p.h. per sec. The retardation of electric and steam passenger trains is usually 1·5 m.p.h. per sec., and for steam goods locomotive 0·7 to 0·8 m.p.h. per sec. Tests should be made with the normal or service braking, and also with the emergency or sudden application of the brakes without any preliminary braking being made, to find in what lengths the trains can be stopped. The tests should be made with trains of different weights, if necessary, travelling at varying speeds and as far as practicable on a level grade. Having arrived at average braking lengths for the different speeds, it is necessary to add certain percentages for imperfect brake adjustment, slippery rails, different weight of trains, etc. ; and from these final figures it is usual to plot curves on squared paper for use in calculations. To compensate for rising or falling grades, a table of compensating factors is used in conjunction with the curves, separate tables being used for service and emergency braking.

Other factors that require to be settled by the different departments concerned are the average length of the trains and the time allowed for station stops.*

* On these and other points some useful information may be obtained from " The Signalling of a Rapid Transit Railway," by H. G. Brown (*Jour. Inst. El. Eng.*, Vol. lii, pp. 545 *et seq.*).

Plotting Signal Locations. From the preceding paragraphs it will be seen that the following items are required before any signals can be plotted—

(1) A scale plan showing the line with stations, grades and curves plotted on squared paper to a scale chosen according to the length to be signalled and headway required, so that the plan is not unduly long. Paper ruled with 10 squares to the half-inch will be found useful for this purpose. Usually, this plan is copied from (2).

(2) A longitudinal scale plan showing track arrangements with bridges, level crossings, grades, curves, etc. Scale 1 in. = 200 or 400ft.

(3) Time allowed for each station stop.

(4) Headway of traffic.

(5) Average length of train.

(6) Permissible and possible speeds over the section to be signalled.

(7) System of signalling to be installed, and whether two- or three-position signalling is to be adopted ; also whether provided with an overlap or a full block section.

(8) Whether automatic train control is to be installed in conjunction with the signals.

(9) The length of time taken for the signal mechanism—and train-stop mechanism, if installed—to operate to the " caution " or " proceed " position.

(10) Deceleration curves for service and emergency braking with compensating factor tables.

Having obtained the plans and information necessary for the above, a tentative location of signals may be made on plan (2) allowing for obstructions, such as bridges, station buildings, etc., and giving protection to level-crossing gates, junctions, etc. These locations should then be plotted accurately on the squared paper, the abscissae being used for the longitudinal distances in feet or yards, and the ordinates for the time in seconds. The time taken for a train to pass from one station to another should then be plotted, showing the deceleration of speed when entering a station, the station stop, and the acceleration of speed from zero on leaving the station. This is carried out for the entire section and results in diagonal lines running across the plan showing the traffic running, as in Fig. 33.

The control and overlap for *A* (Fig. 33) extends up to *C*, but the track-circuit between *B* and *C* will not clear until the tail of the train has passed *B*,

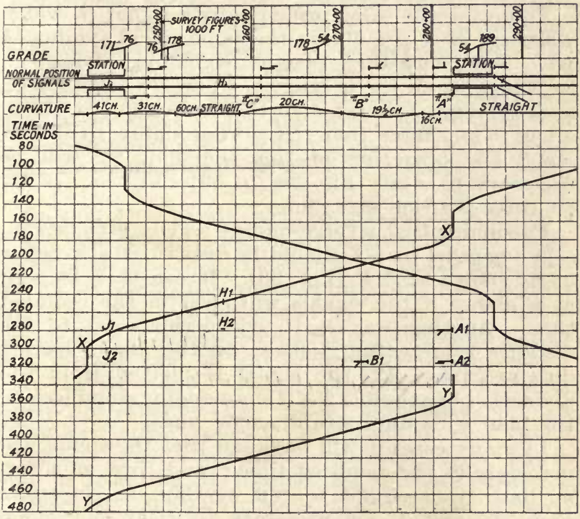


FIG. 33.—GRAPHICAL METHOD FOR PLOTTING AUTOMATIC SIGNALS.

This figure is reproduced from a drawing in which the squares here shown were of ½-in. side, each side being divided into ten equal parts forming $\frac{1}{20}$ in. squares.

and therefore the head of the train will be at some distance from *C*, say, a distance of 420 ft. It is, therefore, necessary for a point *H* to be considered as the clearing point for signal *A*. Marking *H*1 on the diagonal line directly underneath, we must allow a certain time to elapse for the operation of the signal and train-stop mechanisms, and also to allow a sufficient distance for the driver to see the arm at the " caution " or " clear " position. If we allow 30 sec. altogether for this, we then get $H2$ directly under $H1$, but 30 sec. later. Tracing the abscissa back to $A1$, we plot the signal symbol shown.

Following the same principle with signal B, which will clear at J, we obtain the same signal symbol at $B1$. Now, with three-position signalling, A may go to 90 deg. from the horizontal when B is at 45 deg., and, therefore, we get a further indication at $A2$ in about 5 sec. later than $B1$. Thoroughly to understand the operation of this signalling, it will be necessary to study Fig. 36 (p. 59) and Chapter IX on three-position signalling.

Presuming that a three-minute service is to be run, a line parallel to XX should be drawn 180 sec. below it, as shown at YY (Fig. 33). It can then be seen at a glance if the signals will clear in the required time. Another way is to use dividers set to the distance representing 180 sec. on the plan ; having obtained, say, $A2$, the signal is plotted from the dividers above the line XX, thus avoiding complicating the plan with duplicate diagonal lines.

In many cases it will be found that the signal will not clear in the required time ; and then an intermediate track-circuit for an overlap, as shown in Figs. 34 and 35, is necessary to clear the signal earlier, or, maybe, the re-location of, or additional, signals will be necessary, before the operation of the signals will give the required service.

Such a plan shown on the squared paper establishes a record of the signal clearances, and is always available should the train service require a closer headway.

" Normal Clear " and " Normal Danger " Systems. The former is the more usual system adopted by all railways for automatic signals, but one instance of the latter method is in service in England on the North-Eastern Railway between Alne and Thirsk. In the " normal clear " system, the signal arms are in the " proceed " position when the section ahead is clear ; but in the " normal danger " system, although the section ahead is clear, the signal arm will remain in the " stop " position until a train is approaching in the same direction, when the arm will go to the " proceed " position. The arrangement of the latter closely follows manually-operated signalling, but, whilst not saving any power on a closely-spaced service, is additionally expensive on account of extra relays and wire being required to give the approach indication circuit. This, of course, adds a complication from which the " normal clear " system is free.

On the other hand, the " normal clear " system is a straightforward method of control, and is more rational in principle, inasmuch as when the block section is clear, the signal protecting that section announces the fact and displays a " proceed " indication. Thus it comes about that practically all signals now installed are on the " normal clear " system.

It may be added that the amount of power consumed in holding the signal mechanism in the " caution " or " proceed " position is very small compared with the initial consumption of power used in operating the mechanisms to those positions.

Overlaps. In many cases, the distance between signals is too great to give as quick a succession of trains as is required. This is due to the distance a train has to travel before the signals in its rear will pass again to the " clear " position. It is, therefore, necessary to divide the section to give a quicker clearance. The distance of the overlap must remain sufficient to give the emergency braking length required dependent on the normal speed of the trains passing over the section. Referring to Fig. 34, we have a section between *X* and *Y* required to be signalled for a three-minute train service, and using two-position signals. As there is a station at *Y*, time must be taken in stopping and starting the train, in addition to the station stop. Under the conditions as shown at *A*, signal S100 will take 200 sec. before the arm will clear, and this exceeds the 180 sec. available (as a maximum) for clearance in a 3-min. service. Assuming that section S100T is of sufficient length to give accommodation for the train standing in the station, and at the same time allowing for emergency braking distance by putting block joints at *J*, this will enable S100 to clear when the train has passed *J* ; i.e. in, say, 140 sec. It should

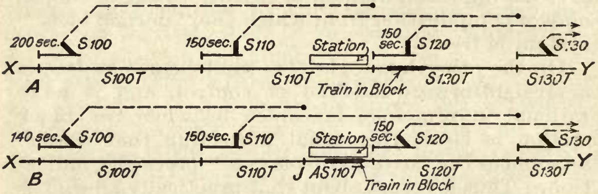


FIG. 34.—CONTROLS FOR TWO-POSITION AUTOMATIC SIGNALS.

be remembered that spacing between signals should never be less than service-braking distance, which is, of course, a much greater length than the emergency braking distance.

Automatic Signalling Systems. There are several means by which automatic signals may be operated. As stated in Chapter II, the track-circuit is used for the control of these ; treadles and the like are all being superseded on modern installations. The question of suitable power being obtainable is a matter which must first be settled. In many country districts where no electrical power can be obtained from an outside source, the railway administration may be compelled to install a generating plant, unless primary batteries are used. Primary battery installations are in service in many places, and the signal motors work under a low-voltage pressure. On the other hand, the working costs of primary batteries are high compared with a high-voltage transmission system from which tappings are taken for the signalling requirements. Station lighting, etc., may also be obtained from the same transmission mains.

The four automatic signalling systems in service in England are as follows, given in the order of the number of miles of track so protected throughout the world: (1) All-electric signals. (2) Electro-pneumatic signals. (3) Low-pressure pneumatic signals. (4) Electro-gas signals.

Power for all-electric signals may be obtained from primary or secondary batteries and direct- or alternating-current generators, the signal mechanisms operating at pressures of from 10 V to 110 V.

Electro-pneumatic signals require—in addition to the electrical control, which may be by any one of the methods used for all-electric systems—an air main running the entire length of the section to be signalled, and carrying air at about 60 lb. per sq. in., which is supplied by air-compressors installed at convenient points.

Power for low-pressure pneumatic signals is obtained from an air main, kept at a pressure of about 15 lb. per sq. in., running the entire length of the section. The controlling energy is obtained generally from primary batteries.

Power for electro-gas signals is obtained from cylinders containing carbonic acid gas, the controlling of which is effected by primary batteries.

Two- and Three-position Signals. In Fig. 34 is shown the method by which a two-position signal is controlled, the dotted lines showing the extent of the track-circuits controlling the signal, the aspects of the signals showing the arm in the horizontal position, with a red light for the night indication for "danger," and the arm at 60 deg. below horizontal or 60 deg. above horizontal, with a green light for "clear." In many cases, it is necessary that a driver should be given advance information of the signal next ahead of the signal he is approaching, and this is done by fixing a repeating signal arm under the stop-signal arm (as shown in Fig. 35). The control for this arm is taken through contacts fixed on the upper arms of the next two stop signals and it is only when these two arms are " off " that the repeater arm mechanism will operate. The method of control for the upper arm is shown in dotted lines, there being no overlaps ; this is typical of the low-pressure pneumatic signals in service on the London and South-Western Railway between Woking and Basingstoke. The upper stop arms are generally

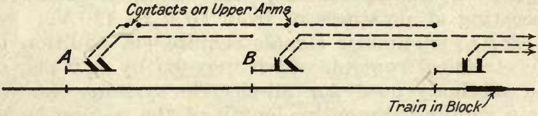


FIG. 35.—CONTROLS FOR TWO-POSITION SIGNALS AND REPEATERS WITHOUT OVERLAPS.

square-ended, and the lower distant arms have fish-tailed ends similar to the ordinary mechanical distant arm. The distinction for the latter at night is obtained by using a yellow light when the arm is at the horizontal position, and green for the " proceed " indication.

With three-position signalling, however, the same kind of information is given without the aid of additional mechanisms, arms, and wiring. In *A* (Fig. 36) we have a train occupying the track section S130T, and this causes signals S120 and S130 to remain at " danger." S110 control is taken up to S130 and the signal arm is shown in the 45-deg. position, and S100 is therefore shown in the 90 deg. position. As soon as the train clears S130T, S120 will go to 45 deg. and then S110 will go to 90 deg. Diagram *B* (Fig. 36) shows the result of dividing S130T into two sections ; when the train is occupying AS130T, S120 can go to 45 deg., allowing S110 to go to 90 deg. earlier than is the case in *A*, and consequently any following train will not be checked, thus allowing a closer headway.

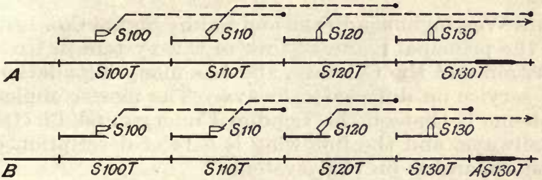


FIG. 36.—CONTROLS FOR THREE-POSITION, UPPER-QUADRANT SIGNALS.

Upper and Lower Quadrant Signals. During recent years, the signal-arm working in the upper quadrant position has been extensively adopted. In mechanical signalling practice it was found necessary to counter-weight the spectacle end of the arm so that any snow or other foreign matter on the other end would not cause the arm to show a false "clear" indication by the weighting down of that end. As a further precaution against this, the upwardly inclined was introduced on American and Continental railways, and this has now become standard practice in automatic signalling. From personal experience, the author considers that this gives the better aspect, from a driver's point of view, especially for three-position signalling. Although three-position lower quadrant signalling is in service in the United States, it has not been adopted in recent installations.

In the following chapters, instances are given of the different systems in service, special attention being paid to the methods which will probably be adopted for all future work.

CHAPTER V

ELECTRO-PNEUMATIC AUTOMATIC SIGNALS

THE Westinghouse Brake and Saxby Signal Co., Ltd., is the principal manufacturer of this system in Great Britain and the Colonies, and has many installations in service on different railways. The most complete scheme is that on the London Underground Electric Railways, and the following is a brief description of the apparatus on that system.

Electro-pneumatic Motors. The track-circuits are similar to those illustrated in Fig. 13 (p. 25), using polarized relays. The operating power is compressed air, at a working pressure of about 60 lb. per sq. in., which is fed into the air main at the different sub-stations on the system. Smaller pipes are taken from this main to the signal and train-stop electro-pneumatic motors, one of which is shown in section in Fig. 37. This consists of an electromagnet, and piston and cylinder. When the track relays *A* and *B* (Fig. 13) are energized, current flows into the magnet *M* (Fig. 37); the armature is attracted, and this opens a pin valve *PV* and at the same time forces down a spring, allowing air to pass from the air pipe into the cylinder, where it presses out the piston. A rod connected to the other end of the piston is coupled to the signal or train-stop mechanism and, when the piston moves, the mechanism operates. Immediately the track-circuit is occupied, the electrical circuit is opened, the armature is released, and air is cut off from the air pipe. The weight of the mechanism then forces the piston back and the signal arm goes to "danger." The cylinder makes a good pneumatic cushion and allows the mechanism to go to rest without any jar or shock.

Signals. There are several types of signals operated by this means to meet different conditions of service and location. For outdoor working, a semaphore arm is used, and the motor is placed underneath the arm as shown in Fig. 38. The connecting rod operates the spindle carrying the signal spectacle, and when the piston is forced out, the spindle is turned and the arm lowered. To meet with the requirement of an upwardly inclined arm, a different arrangement is provided as shown in Fig. 39, the case containing the piston, cylinder, and valve magnet being then fixed to the side of the signal post with the arm below.

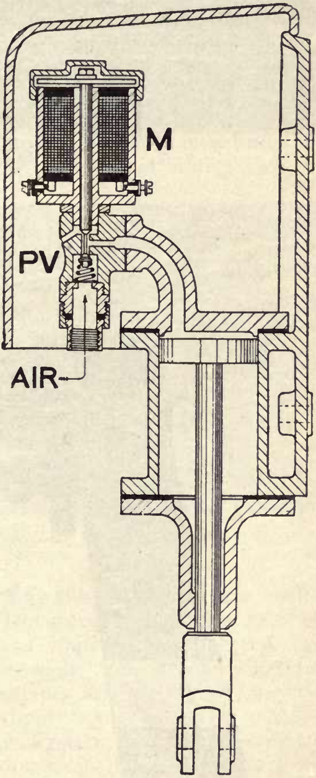


FIG. 37.—SECTION OF ELECTRO-PNEUMATIC SIGNAL MOTOR.

Special types of signals are used in tunnels and "tubes." These are light signals, in the sense that only light indications are given, and the signals are of specially compact construction to suit the limited clearance of the tunnels.

Train Stops. The electro-pneumatic train-stop which works in parallel circuit with the signal is shown in Fig. 40, and is provided with a motor

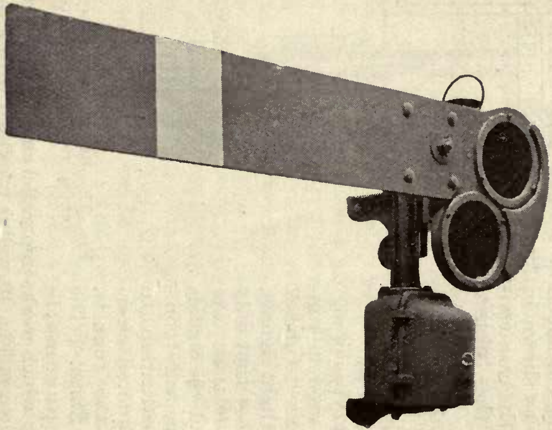


Fig. 38.—Semaphore Signal and Electro-pneumatic Motor.

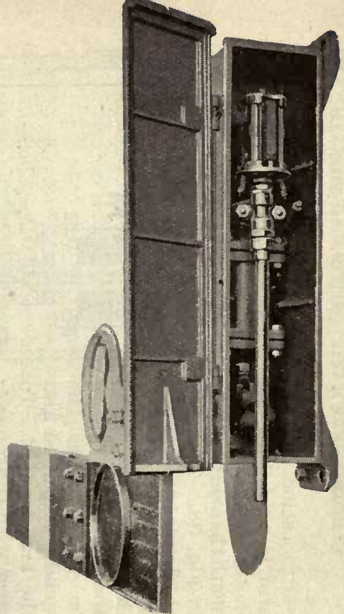


Fig. 39.—Upper Quadrant Electro-pneumatic Signal.

similar to that of the signal. The end of the piston is connected to a long rod, which operates the train-stop arm. When the signal is at " danger," the arm stands in a vertical position as illustrated ; and fitted to the train is a cock (connected to the brake apparatus), the handle of which is pointing down to the track (Fig. 66, p. 100). Should the driver over-run the signal, this handle strikes the train-stop arm and the brakes are applied. When the signal is at " clear "

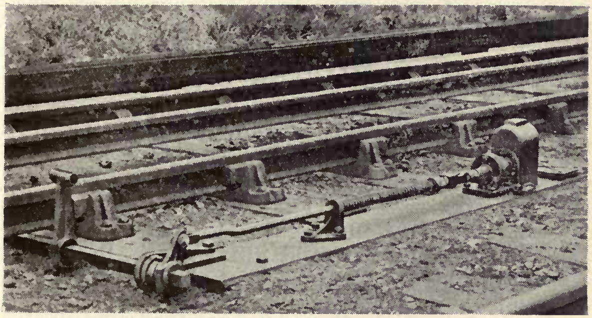


FIG. 40.—TRAIN STOP OPERATED BY ELECTRO-PNEUMATIC MOTOR.

the arm is turned, and thus the train can pass without any interference. During the time the arm is in this latter position, a helical spring fitted on the rod is under compression. On de-energization of the magnet, the air escapes and the spring moves the rod back to the " danger " position.

A.C. Electro-pneumatic System. A later development is the a.c. electro-pneumatic system, which is in service on the Central London Railway, where the signals are operated electrically, but the train-stops are operated by air. On this railway, the track-circuits are operated by alternating current, this being necessary because both rails are used for traction return ; in consequence, impedance bonds are required. The track voltage fed from the transformer varies from 2·5 V to 4·5 V according to the length of the section, and is taken from a 6 V winding on the transformer through thermal regulators on to the rail. Single-element vane track relays, similar to that shown in Fig. 24 (p. 40) are used.

The apparatus used for electro-pneumatic signalling is simple, and there are few parts to cause failure in either the signal or train-stop mechanisms.

CHAPTER VI

ELECTRO-GAS AUTOMATIC SIGNALS

An installation of this system was put into service on the North-Eastern Railway between Alne and Thirsk, a distance of 11 miles, in 1905. This was installed by the Hall Switch and Signal Co., of Garwood, N.J., U.S.A. ; and although there is little probability of any further sections being so signalled, the installation is interesting on account of the operating power and the use of bottom-of-post mechanisms, and also because the signals are worked on the " normal danger " system.

The signal mechanisms are placed at the bottom of the tubular signal masts, and are operated by liquified carbonic acid gas. This gas is stored in two removable steel cylinders placed at the foot of the signal mast, the cylinders being used alternatively, and each containing sufficient power for about 7,000 signal operations at a pressure of 50 lb. per sq. in. The cylinders are re-charged at some chemical works at intervals of from 7 to 10 weeks. By this means, a spare cylinder is always available.

The track-circuits are fed from two gravity cells connected in parallel, and 4-ohm track relays are used ; the average length of each section is 1,200 yds., with overlaps of 400 yds. long placed in advance of each signal. Distant (or, more correctly, "repeater") arms are placed under the stop-arms. The mechanisms operating these arms are placed in the base of the mast, at the side of which are housed the cylinders containing the liquid carbon dioxide.

The lower portion of the base contains the batteries. The operating cylinders are connected to the upright rods, in turn connected to the signal arms, and the pistons are fixed. When the signal-control circuit is closed, an electro-magnet is energized and the armature allows the supply valve to be opened and the exhaust valve to be closed, thus allowing gas to enter the operating cylinder, forcing the cylinder up and so lowering the signal arm. When the control circuit is opened, the magnet is de-energized, freeing a latch which holds the signal arm in the "off" position, and allowing the arm to go to "danger" by gravity. The cylinder acts as a dashpot on account of a check ball valve partly closing the exhaust and preventing any jar to the mechanism.

Fig. 41 is a diagram showing how signals ahead are operated on the "normal danger" arrangement. The track relays at each signal location are provided with two front or upper contacts and one bottom

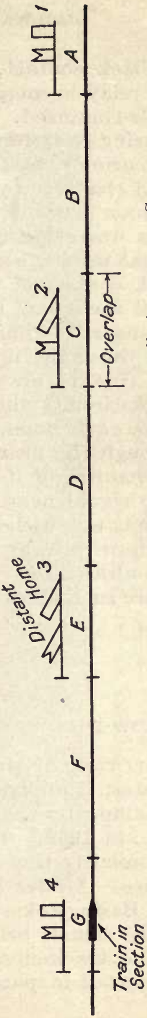


FIG. 41.—ILLUSTRATING CONTROL OF "NORMAL DANGER" AUTOMATIC SIGNALS. (*North Eastern Railway*)

or back contact, the former making contact when the relay is energized, and the latter when the relay is de-energized. At each signal location there is a clearing relay for operating the home signal arm, and a clearing relay for the distant signal arm, the latter relay having two coil windings of approximately 4 ohms and 100 ohms. The control for the magnet coils operating the gas supply valve to the home-signal mechanism for signal 2 is taken through the back contact of the track relay of section *G* ; thus, until section *G* be entered, the arm will remain at "danger." Similarly, a train entering section *E* will cause the upper arm of signal 1 to be lowered. All this is always providing that the respective track-circuits ahead are clear.

As each home signal is lowered, a circuit, taken through the arm contact, is closed to the operating mechanism of its corresponding distant arm on the stop signal next in the rear.

It is not without interest to note that the North-Eastern Railway Company is using electro-gas signals in substitution for mechanically operated signals where such are a long distance from the signal-box.

CHAPTER VII

LOW-PRESSURE PNEUMATIC AUTOMATIC SIGNALS

A SECTION of six miles of the London and South-Western Railway was equipped with this system of signalling by the British Power Railway Signal Co., Ltd., in 1902. The method of control of the signals is similar to that shown in Fig. 35, as no overlaps are in use. A later installation is that between Woking and Basingstoke, a distance of 24 miles, the operation of the signals being the same.

The track-circuits are fed by two gravity cells connected in parallel, and the relays are similar to

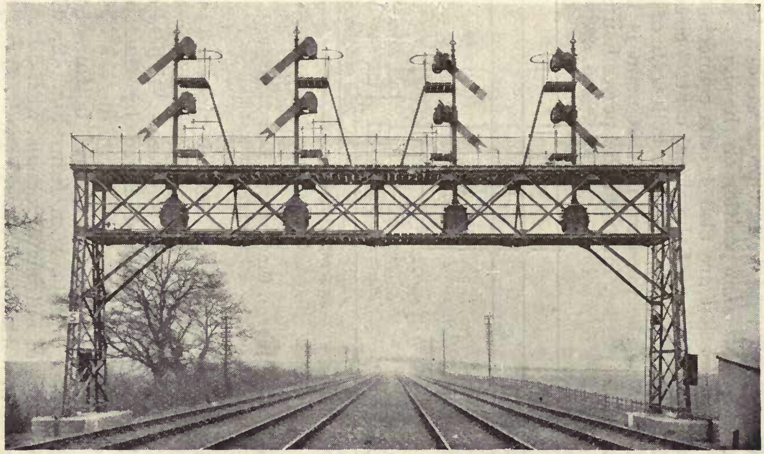


FIG. 42.—FOUR-TRACK SIGNAL BRIDGE WITH LOW-PRESSURE PNEUMATIC SIGNALS.
(*London & South Western Railway*).

that shown in Fig. 11 (p. 20). The resistance of the windings of the track relays varies from 3½ to 9 ohms, according to the length of the section. The track relays are housed in dust-proof wooden boxes mounted in a convenient position on the signal post. At the same location are also 4 cells connected in series for the operation of the signal control circuit.

An air main pipe runs the whole length of the installation, and the pressure in this main is kept at about 25 lb. per sq. in. from the power-house at

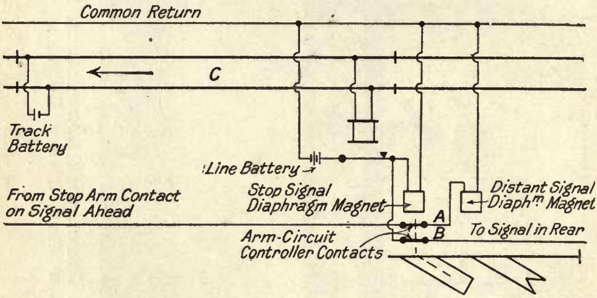


FIG. 43.—CONTROL CIRCUIT FOR LOW-PRESSURE PNEUMATIC AUTOMATIC SIGNALS.

one end of the installation. Branch pipes are taken from the main to the signal diaphragm valves, which require only 5 lb. per sq. in. to operate. These control valves are opened and closed by the track-circuits.

The signals are operated by bottom-of-post mechanisms, as will be seen from Fig. 42, which shows a bridge of automatic signals, with distant or repeater arms, worked in the lower quadrant position.

The method of control for the diaphragm valves is shown in Fig. 43. As each signal is controlled by only the one track-circuit immediately ahead, there being no overlap, a typical wiring diagram of one signal location is all that is necessary. When the track relay is energized, current flows from the line battery through the relay contact to the diaphragm valve magnet controlling the air pressure to the stop-signal diaphragm. The armature of this magnet is lifted and air passes from the pipe to the diaphragm, and operates the diaphragm piston, which, in turn, forces a crank down and the arm is lowered. The arm, when lowered, closes two contacts mechanically connected to the stop-signal arm. One circuit controlled by this arm-circuit controller is fed from the line battery through the arm contact, then through the line to the stop-arm contact at the signal in the rear, and there the connection is similar to that made and marked as *A* in the diagram. The other contact is used for the incoming wire from the stop-signal arm ahead, and closes the circuit for the diaphragm valve operating the distant signal arm. Thus, assuming that the stop-signal arm ahead is in the "off" position, current will flow from that signal, as at *B*, to the *A* of the signal shown in the diagram.

When a train enters the section *C*, the track relay becomes de-energized and the circuit to the stop-signal diaphragm valve magnet is opened, the armature is dropped, air is cut off from the diaphragm, the piston is released, the air already in the diaphragm escapes by a vent hole, and the stop-signal arm goes to "danger." At the same time, the contacts on the arm-circuit controller are opened and the circuit to the distant signal diaphragm valve magnet is opened, therefore that arm goes to "danger."

As soon as the section *C* is clear, the *B* circuit is operative again and the stop-signal arm is lowered ; but the *A* circuit is not operative until the *B* circuit at the signal ahead is closed.

Fig. 44 shows the arrangement of the magnet with the diaphragm and piston operating the crank connected to the signal-arm rod, with the pipes connected to the air main.

The arrangement of this signalling calls for little electrical wiring, there being only two wires required,

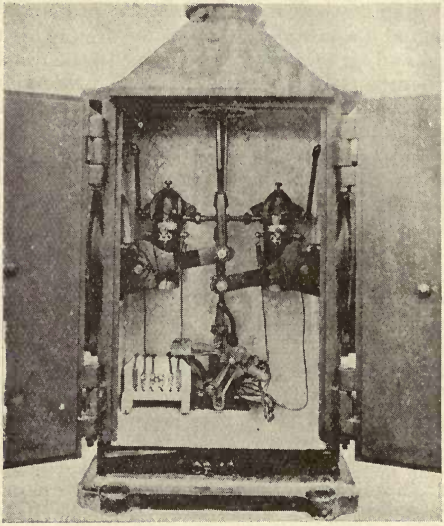


FIG. 44.—MAGNETS, DIAPHRAGMS, ETC., FOR LOW-PRESSURE PNEUMATIC SIGNALS.
For the upper stop signal arm on the right and for the lower distant arm on the left.

one for the common return and the other for the line wire operating the distant signal arm.

CHAPTER VIII

ALL-ELECTRIC TWO-POSITION AUTOMATIC SIGNALS

THE Metropolitan Railway, between Baker Street and Harrow, also the East London Joint Line, were signalled under this system by the Westinghouse

Brake and Saxby Signal Co., Ltd. Part of the former installation is equipped with direct-current signalling apparatus, and the remainder with alternating-current signalling apparatus.

Circuits and Operation. The track-circuits for the former section are similar to that shown in Fig. 13

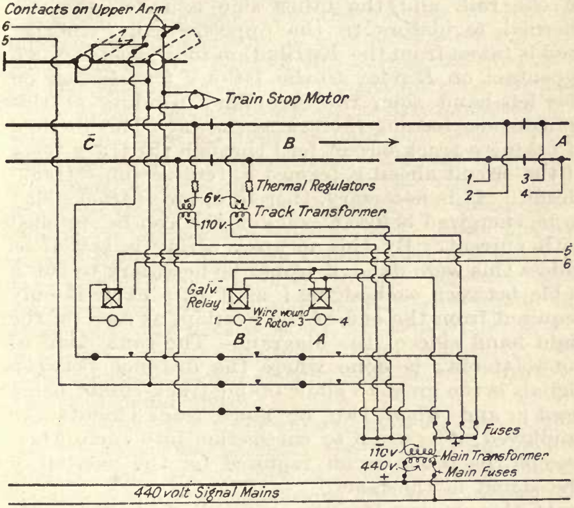


FIG. 45.—SIGNAL LOCATION WIRING A.C. TWO-POSITION UPPER QUADRANT SIGNALLING.

(p. 25), and the signal controls are taken to d.c. motors operating the signal mechanisms. As a negative return rail is used for traction purposes, no impedance bonds are required. The a.c. track-circuits are connected as shown in Fig. 45. Galvanometer track relays, of the same type as shown in Fig. 22 (p. 37) are used. From Fig. 45 it will be seen that a signalling main, kept at a pressure of 440 V, is fed into a transformer which reduces the voltage from 440 V to 110 V, and the two ends of the secondary winding are taken to a positive fuse distribution panel and a negative bus-bar. A 110 V feed is taken from the positive side to a track transformer, which reduces the voltage to 6 V. One side of the transformer secondary is connected directly to the rail, and the other side is taken through thermal regulators to the opposite rail. Another feed is taken from the distribution fuse panel through a contact on *B* relay to the 110/6 V transformer on the left-hand side, the secondary winding of this transformer feeding *C* track as shown. This method of taking a track-circuit feed through the track relay of the circuit ahead is termed a " cut section " track-circuit. It is necessary, therefore, for *B* track relay to be energized before *C* track-circuit can be supplied with current. By this means, wiring is saved, as unless this were done, it would be necessary to run a cable between each signal ; as it is, a cable is only required from the end of the overlap, as seen on the right-hand side of the diagram. The same kind of cut-sectioning is done where the distance between signals is too great to allow of one track-circuit being used ; and when two or more track-circuits are employed, it is usual to cut-section into each other, except the track-circuit required for the overlap of the signal in the rear.

At the overlap location, wires 1, 2, 3, and 4 are brought to the signal location and connected to the rotor as described in Chapter III. Energy is constantly supplied to the local windings of the track relay from the 110 V distribution. Assuming that tracks *A* and *B* are unoccupied, the relays will be energized and the contacts closed. A feed then flows from the positive distribution panel, through contacts on *A* and *B* track relays, direct to the signal motor operating the mechanism for the stop-arm. A tap is taken from this wire to the train-stop motor, and the return from the train-stop and signal motors is taken through the relay contacts to the 110 V negative bus-bar. This completes the circuit for the signal and train-stop motors.

As soon as current flows to the signal motor, a feed is tapped from the control circuit through an arm-circuit controller contact—which is operated mechanically by the signal arm—and is taken to the signal in the rear. For the purpose of identifying the circuit, the wire is numbered 6 on the left-hand side of Fig. 45, and this corresponds to the 6 on the right-hand side. The circuit goes through the windings of the rotor of a galvanometer line relay—the wire of which is finer and composed of more turns than a track relay—through the stator windings in series, and returns via wire 5 to the negative bus-bar. When this relay is energized, a contact is closed and current flows from positive energy through the relay contact and a contact on the arm-circuit controller to the repeater-signal motor. The two contacts on the arm-circuit controller are only closed when the stop signal arm is in the "clear" position. The return for the repeater-signal motor is connected to the return for the stop-signal motor.

Immediately a train enters track *B*, the *B* track relay becomes de-energized, the contacts are opened, and the stop signal goes to "danger," opening the arm-circuit controller contact and thus causing the repeater arm also to go to "danger." When the train enters track *A*, that relay becomes de-energized. When track *B* is cleared, the relay picks up; but track relay *A* is not energized until the train has cleared the track ahead—corresponding to track *C* in Fig. 45—on account of its being a cut-section track-circuit.

Before leaving the description of the control circuit, attention should be paid to Fig. 46, which shows a typical location of signal apparatus. On the right-hand side facing the track is the main

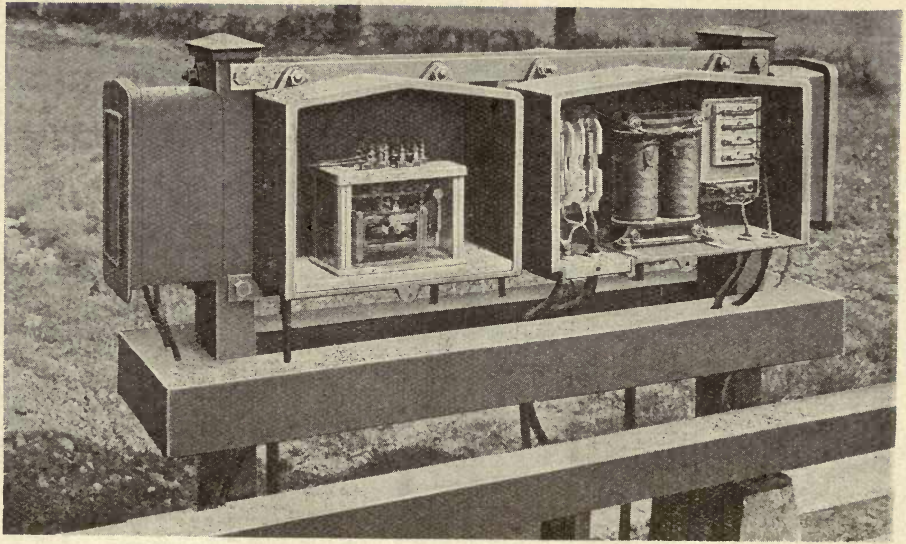


FIG. 46.—TYPICAL LOCATION OF SIGNAL AND TRACK APPARATUS.

440/110 V transformer of about 0·6 kVA capacity, with fuse and bus-bar distribution. At each end of the stand are placed track feed-boxes similar to that shown in Fig. 47. At the back are two cast-iron cases containing the track relays, and in front is the line relay operating the repeater signal mechanism. All cables are carried in trunking as seen at the bottom of Fig. 46, and a ring of trunking is placed around the stand for the local wiring. Fig. 47 shows a track feed-box with the transformer behind the thermal regulator base, the connections for which are seen at the bottom of the case, also the connections going from the thermal regulator terminals to the track.

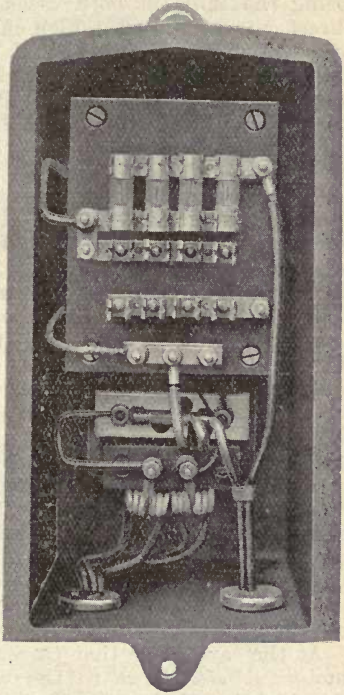


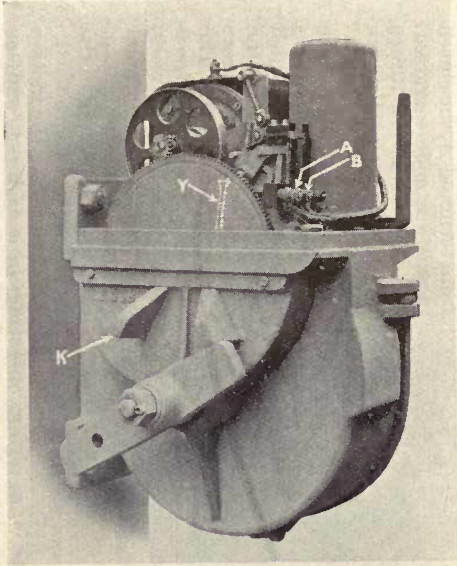
FIG. 47.—TRACK SERVICE CASE; WITH TRANSFORMER, THERMAL REGULATORS, FUSE BASE AND TERMINAL BOARD.

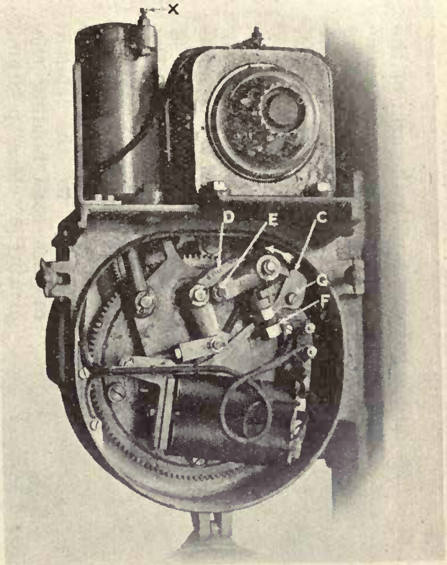
Westinghouse Brake and Saxby Signal Machine. Two views of this signal mechanism are shown in Figs. 48 and 49. The essential parts are the motor, train of gears, and motion plate fitted with the clutch mechanism. The motor may be operated by either direct or alternating current, the mechanism being the same in both cases. When low-voltage direct current is used, a high efficiency motor is provided with ball bearings and copper brushes, the latter being enclosed under a glass cover, as seen in Fig. 49. With alternating current, induction motors with plain bearings are used. Each motor is supplied with a brake drum and pinion wheel engaging with a train of gears.

When the track relay contacts are closed, current flows to the terminal marked *A*. Terminal *B* is connected to the motor. Each terminal is provided with contact springs, and a bridging contact closes the circuit from supply to the motor. On the rotation of the motor, the small pinion wheel operates the main gear wheel, seen in the lower portion of Fig. 48, in a counter-clockwise direction. This gear wheel is provided with six rollers, which are, in turn, brought into engagement with a pawl situated at the rear of the motion plate on which the clutch coils and clutch mechanism are mounted. The pawl is attached rigidly to the crank arm *E*, a roller being fitted to the end of this arm. The motion plate and the operating crank fitted outside the case are rigidly connected to the same spindle, and, with the movement of the motion plate, the operating crank connected to the signal arm is moved, thereby raising the signal arm.

At the same time that current flows to the signal motor, it also flows to the clutch magnets from terminal *A*, and the armature, being attracted to the pole faces, holds the crank arm *E* by means of another crank *D*. This results in the pawl being held in such a position that the roller on the main gear wheel, when rotated, will engage with it, and thereby cause the motion plate to move with the gear wheel.

As soon as the motion plate has travelled approximately 60 deg., a small roller *C* on the end of the





WESTINGHOUSE BRAKE AND SAXBY SIGNAL MACHINE.

FIG. 48.—TOP COVER REMOVED SHOWING CUT-OUT AND BRAKE.

FIG. 49.—COVERS REMOVED SHOWING CLUTCH MECHANISM, MOTOR AND BUFFER CYLINDER.

arm *G* comes into engagement with the arm of the cut-out between terminals *A* and *B*, thus cutting off the current from the motor. At the same time, this releases the brake shoe which presses on the brake drum of the motor, causing it to stop almost instantaneously and preventing any movement in the opposite direction. Although current is cut off from *B*, current still flows from *A* to the clutch magnet coils holding the arm in the "clear" position.

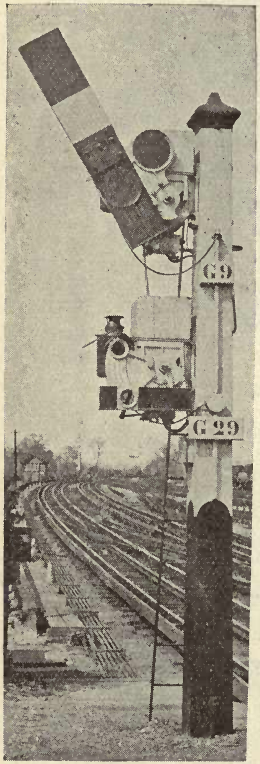


FIG. 50.—UPPER QUADRANT ELECTRIC SIGNALS. MAIN AND SHUNT ARMS.

When the track-circuit is "shorted," power is cut off from terminal *A*, the clutch magnets are de-energized, and the armature drops away. This releases crank *D* from the roller *E*, allowing the latter and the crank to which it is attached, and also the pawl which was in engagement with the roller on the main gear wheel, to be freed. The motion plate being freed from all holding devices, is restored to its original position by the weight of the signal arm going to the "danger" position.

Connected to the motion plate is a piston operating in a dash-pot and, as the motion plate is moving to the "danger" position the piston is forced upwards, compressing sufficient air to form a pneumatic cushion. The amount of cushioning can be regulated by adjusting the screw marked *X*.

During the return of the motion plate, the operating arm for the cut-out is moved back to its original position by roller *G*, thus closing the motor circuit, and also removing the brake shoe from the brake drum. On the motor being again operated, another roller on the gear wheel becomes engaged with the pawl ; thus, for one revolution of the main gear wheel, six complete operations of the signal machine are made. Fig. 50 shows one of the signals fixed on the Baker Street and Harrow line.

CHAPTER IX

ALL-ELECTRIC THREE-POSITION AUTOMATIC SIGNALS

THE first section of railway in England to be operated by three-position automatic signalling was that brought into service, in 1920, on the Great Western Railway extension from Shepherd's Bush to Ealing. Many miles of track, however, are protected by this system on the railways in America and Australia, and the system has many features that recommend it to signal engineers and operating officials. In practically all recent installations, the signal arms work in the upper quadrant position, although previously there were some operated in the lower quadrant position. In Great Britain—and the majority of the British Colonies follow the same practice—the arms work in the left-hand side quadrant and, as the train approaches, the arm is on the left-hand side of the post. In America, the direction of the traffic is reversed, and the arms work on the right-hand side quadrant and are on the right-hand side of the post. This is seen clearly from

Fig. 51, which shows the two practices side by side. The same ruling applies to single-line signalling.

As mentioned in Chapter IV, three-position signals give an indication of the position of the arm of the signal ahead, without the aid of a repeater arm. Also, the three-position signal is a means of informing the driver of the speed at which he may travel. Studying Fig. 52, aspects 1, 4 and 7 in the second column are without speed signalling indications and can be compared with the method of control shown in Fig. 36. Aspects 2, 3, 5, 6 and 8 include speed signalling indications. In the third column is shown

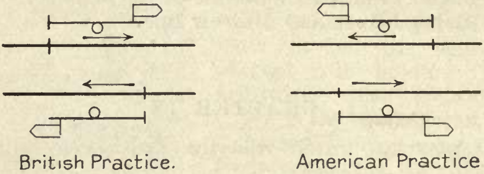


FIG. 51.—BRITISH AND AMERICAN SIGNALLING PRACTICE COMPARED.

the aspect displayed to govern movements under the different conditions. In the fourth column is given the instructions for the driver, etc., to follow when approaching the different signal aspects ; and the fifth column gives the names of each aspect. It will be seen from the first column that three colours are used : red, yellow, and green, for "danger," "caution," and "clear" aspects respectively.

Marker Lights and Their Use. In addition to the semaphore arm light, there may be what is termed a "marker" light placed approximately 7 ft. below the semaphore lamp.

When automatic and manually-operated signals are met by a driver in the course of a journey, it is essential that he should be able to distinguish one from the other. During the daytime he can see any

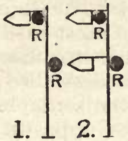
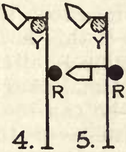
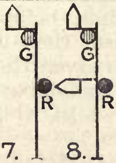
Colour of Light.	Automatic Signals. R = red light. Y = yellow light. G = green light.	Occasion for use. This Aspect will be displayed to govern movements when—	Indication. ForDrivers, Guards and others.	Name.
Red Red	 1. 2.	Section is occupied.	**STOP** then proceed.	**STOP** Signal.
Red Yellow	 3.	Section is clear, but suitable for medium speed only and Signal next in advance is at **STOP**	Proceed at medium speed prepared to stop at next Signal.	Caution Medium Speed Signal.
Yellow Red	 4. 5.	Section is clear; but Signal next in advance is at **STOP**	Proceed **PREPARED TO STOP** at next Signal.	Caution Normal Speed Signal.
Yellow Green	 6.	Section is clear and Signal next in advance is at Caution or Clear for medium speed.	Proceed prepared to pass next Signal at medium speed.	Reduce to Medium Speed Signal.
Green Red	 7. 8.	Section is clear and Signal next in advance is at Caution or Clear for normal speed.	Proceed.	Clear Normal Speed Signal.

FIG. 52—ASPECTS AND INDICATIONS OF THREE-POSITION AUTO-SIGNALS. (*Victorian Railways.*)

distinguishing mark placed on the signal, but at night something in addition must be done. It has been found that using a pointed end for the signal blade of an automatic signal, and a square end for a controlled signal, is the distinction most easily picked up in daytime. At night-time it has become standard practice to use a marker light as described, placing the light vertically in line with the semaphore light for controlled signals, and on the opposite side for automatic signals, giving a staggered effect as shown in Fig. 52. The colour for a marker light for controlled signals is red. Marker lights have not, however, as yet been considered necessary in England, but the day distinction is made by the arms having either square or pointed ends.

One of the reasons why it is necessary for a driver to know the difference between the two classes of signal is this. Presuming he comes to a signal displaying the "stop" indication, if this be an automatic signal he may proceed cautiously after waiting at the signal a predetermined time, ranging from 10 sec. to 1 min., provided that he can see that the section ahead is clear. The cause of the signal being at "danger" may be a signal or track-circuit failure, and therefore delay is reduced by adopting this procedure. On the other hand, there may be a broken rail, or obstruction, other than a train, on the line, and careful watch must be made whilst travelling over the section. If, however, the signal is controlled by a signalman, it may protect certain point movements, and the driver must wait definite authorization from the signalman before he may proceed. If the signal has failed, then it is necessary for written authority to be given the driver to pass a signal at "danger," the signalman taking all precautions to ensure safety whilst this is being done.

Signal Supply Transmission. As stated before, the power for operating any electrical signal may be obtained from primary and secondary batteries, direct- and alternating-current generators. If a long section of signalling is to be undertaken, several interlockings will be affected and, to bring the whole section into line with the automatic signals, it will be necessary for the interlocked signals to be electrically controlled and operated. The methods for doing this lie outside the scope of this volume, but the question of power supply must be studied.

Primary battery signals are self-contained, and should one battery fail, only one or, at the most, two, signals will be affected. The cost of maintaining and renewing cells on a long section of signalling is, however, a large item, and might be proved excessive. The use of secondary batteries reduces this cost, but arrangements have to be made to charge the batteries ; this is not always an easy matter and, if special plant would have to be installed for the purpose, it is a question whether it would not be better to take power straight from the generator. With battery-operated signals, the motors are generally run on from 10 V to 12 V.

Coming to machine-generated power, direct-current energy is somewhat wasteful when used in signalling work, as resistances have to be inserted to reduce the voltage to feed track-circuits, even with a comparatively low-voltage transmission, whilst a high-voltage transmission is out of the question. Unless a very big drop of potential is allowed, sub-stations will be required at frequent intervals. Alternating-current energy is very adaptable for signalling purposes, and meets the service demands very efficiently, but it is not always available.

Whilst any one of the four methods may be utilized to the best advantage under different conditions, it is more particularly alternating-current transmission apparatus that requires to be described, as the other methods follow ordinary electrical practice.

Alternating-current Signal Supply. One of the first things to be decided is the transmission voltage. Voltages ranging from 440 V to 4,400 V are in service, but the most prevalent voltage is 2,200 V. The usual calculations must be made to find out what cross-sectional area of copper will be required to carry the load. The signalling load is comparatively low, as each signal location requires only about 0·6 kVA on the 110 V secondary side. The author has a case in mind where a two-minute train service was required over a distance of about 3 miles of double track involving 33 signals, and the total load on the 2,200 V mains was only 17·5 kVA with all signals clearing, and 4·1 kVA with 10 per cent of the signals clearing and the rest at "clear." However, the station and signal cabin lighting may be taken from the same transmission mains and the load will then be increased.

As is well known, the higher the current value, the larger the section of copper required for the mains. If the voltage be increased, the current for the same amount of power at the end of the line is lowered, and the size of the copper can, therefore, be reduced, thus lowering the cost of the mains. On the other hand, the transmission arrangements must be safeguarded and the apparatus at the transformers will be more expensive, so that the reduction in cost of the mains may not be balanced by the increased cost of the special apparatus necessary with higher transmission voltage. It is, therefore, wise to choose a voltage in general use, so that apparatus is easily obtained, unless the installation is on such a scale as to warrant special apparatus.

The next decision required is the periodicity. This is generally 25 cycles per sec. for signalling on d.c. electric and steam roads, and 60 cycles per sec. for signalling on a.c. electric roads, but different periodicities are in service. Thus it may be necessary to deviate from usual practice in order to make use of an outside source of supply. The periodicity should not, however, be less than 25 cycles per sec., if lighting is to be served from the same supply.

The transmission mains may be either bare or insulated overhead wires, or insulated cable run in trunking or conduits. If overhead wires be installed, suitable arrangements must be made to prevent interference with telegraph and other circuits. It is not always necessary for a special pole line to be erected for the transmission and signal wires, although this is done in many cases, and is probably the better practice. If they are run on poles with other wires, the high-voltage wires must be raised sufficiently high to prevent the induction of appreciable currents in the other circuits. This is necessary also to allow the telegraph linesman sufficient clearance to repair any fault on the telegraph wires without danger of electrocution. With surface or underground cable, when single-phase transmission is in use, twin cable is employed, this being well insulated and, in many cases, armour-covered.

The normal allowable percentage loss of voltage in the line with all signals in the " clear " position is 10 per cent. If, after a breakdown, the signals are all clearing the loss will be much greater; but as the signals would be clearing nearest the sub-station first, and gradually working away to the other end, no difficulty is experienced from this. It is possible to use single-, two-phase or three-phase transmission systems. Unless power has to be transmitted over a long distance, single-phase transmission is the most economical. If, however, the power has to be transmitted a distance of 60 miles or more of double track or 30 miles of quadruple track, and station lighting is also taken from the same mains, the economy of copper wire makes three-phase transmission very attractive. This system, of course, calls for special apparatus arrangements at signal location transformers, which are more complicated than with single-phase transmission. The method of connecting the different phases to the transformers must be worked out to give even balancing throughout the system.

Transformers. Main transformers are installed at frequent intervals. In the case of aerial wires, the transformers are mounted on the pole nearest to the signal location, and a platform is provided for use when attention is required at the transformer. With surface or underground cables, the transformers are housed in special cases, fitted with doors which are kept locked unless anyone is working on the transformer. In practically all cases, whatever may be the high voltage, the secondary voltage is 110 V, this having become standard practice for all signalling apparatus. The main secondary winding is arranged with taps so as to give a range of voltages from 125 V to 100 V, thus allowing for any drop of voltage on the mains. In some cases, it is arranged for other secondary windings to be provided, such as may be required for directly feeding the track-circuits, etc.

If no provision is made on the main transformer for feeding the track-circuits, separate track transformers are used, instances of which are given in this book. An illustration of a transformer with 2,200 V primary and one 110 V and two 6 V secondaries is shown in Fig. 53, this equipment being in service on the Victorian Railways. In the transformer case are two single-phase type, oil-immersed, 0·5 kVA transformers placed at the bottom of the case, a terminal board for 125 V, 115 V, 110 V, and 105 V tappings and negative returns being fixed to the upper portion of the transformer, and a thermal regulator base being fixed at the bottom. At the top are three oil-immersed ironclad two-pole switches, the outside ones being non-automatic and connected to the mains, and being used if the cable between transformer locations becomes defective or requires to be worked upon, thus allowing that section to be cut out without interference with the rest of the system. The centre switch is fitted with a two-pole automatic excess current cut-out, and is connected to the transformer through the bifurcating box seen in the centre. Should the transformer be unduly overloaded, the automatic switch is operated and the circuit is broken, until the switch is replaced by hand. Each switch, as can be seen, is numbered for identification purposes. The case is constructed of cast iron

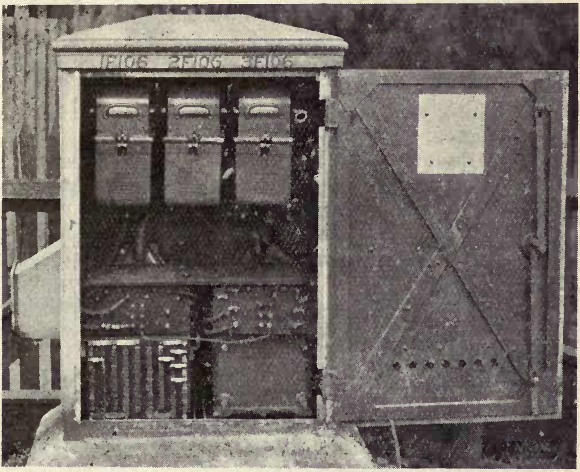


FIG. 53.—2,200 V TRACK FEED BOX WITH SWITCHGEAR. (*Victorian Railways.*)

and sheet steel, and provided with ventilating facilities ; the heat from the transformer being removed by natural radiation from the case. The high-tension cables enter the case on each side, as seen in the illustration.

A.C. Signal Motors. As stated previously, either d.c. or a.c. motors can be used with the same mechanism. For alternating-current signalling, either squirrel-cage induction motors or series commutator motors are used, with either tractive magnet or induction slots as holding-clear devices. From past experience, however, it has been found that for signalling purposes the induction motor is preferable to the commutator motor, being of simple construction and more easily maintained. The requirements imposed on the motor of a signal machine are that it should run at full-load for 4 sec., current being then cut off. These conditions are severe and are best satisfied by the squirrel-cage induction motor, which has no commutator and brushes to give trouble by sparking and to demand continual attention for maintenance.

The amount of power taken by a series commutator motor is less than that by an induction motor, but, as mentioned before, the hold-clear current accounts for the constant load, and this would be the same whatever the type of motor used. The motors can be wound for either single or polyphase operation ; if the former be used, phase splitting is accomplished by inserting a resistance in one of the windings, and the other winding is so arranged as to cause its inductive reactance to be extremely high.

The induction slot used for keeping the signal mechanism in the "caution" or "clear" position works on the induction principle. On the same shaft as that carrying the motor rotor, there is pinned a slot rotor. A separate slot stator is housed in the same cylindrical iron case as the motor stator. When current is flowing through the slot stator windings and there is no torque on the motor shaft, no induced currents will flow in the slot rotor ; but when the arm has been moved to the "caution" or "clear" position and load comes on to the motor shaft, the slot rotor copper bars, arranged symmetrically about the rotor, come within the field of the stator windings, and current is induced into the rotor bars. These currents react on the main stator

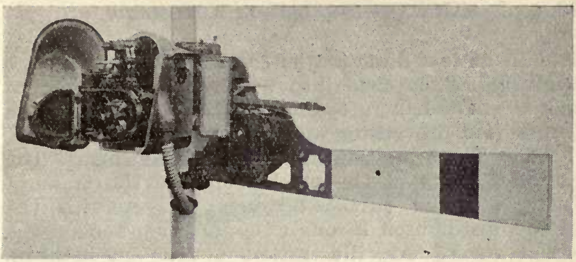


FIG. 54.—THREE-POSITION A.C. SIGNAL MECHANISM.

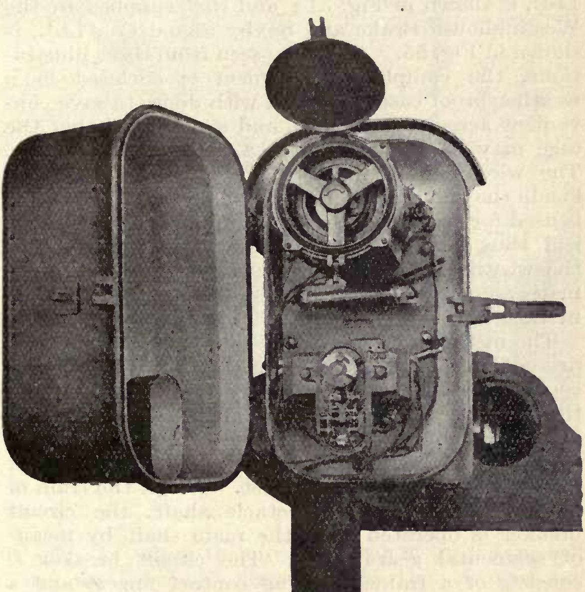


FIG. 55.—THREE-POSITION A.C. SIGNAL MECHANISM.

field in such a direction as to thrust the rotor bars back out of the field into which the torque of the motor shaft has forced them, thus balancing the torque and preventing any movement of the shaft.

A.C. Three-position Signal Mechanisms. The essential parts of the mechanism are the train of gears and the circuit breaker. These, with the motor, are housed in one case and mounted on the signal mast. An illustration of the mechanism, supplied by the British Power Railway Signal Co., Ltd., is shown in Fig. 54 ; and that supplied by the Westinghouse Brake and Saxby Signal Co., Ltd., is shown in Fig. 55. As can be seen from these illustrations, the complete mechanism is enclosed in a weather-proof case, provided with doors to give convenient access to all parts, and so designed that the case may be clamped on to a tubular signal mast. The wires for the mechanism are generally taken inside the tubular mast, and metallic flexible tubing is used for connection between the mast and mechanism, thus ensuring that the wires are not exposed to the weather. In Fig. 56 is seen an ordinary automatic signal in the " caution " position with the marker light.

The method of operation is as follows : The motor drives the train of gears as seen in Fig. 57, a universal coupling being placed between the driving shaft on the gears and the semaphore shaft at *A*, thus imparting movement to the signal arm. Adjusting screws are provided to enable the signal blade to be brought to the correct angle to the post. Whilst the train of gears is turning the spectacle shaft, the circuit breaker is operated from the main shaft by means of segmental gears at *B*. The circuit breaker *C* consists of a frame carrying contact fingers and a revolving commutator, on which are mounted contact segments as required. At the left-hand end is placed the pole-changing apparatus. This is used for reversing the polarity of the line circuit. At the extreme end of the shaft can be seen two Veeder counters for recording all movements of the mechanism to the 45 and 90 deg. positions.

The circuit operation of the pole-changer is shown

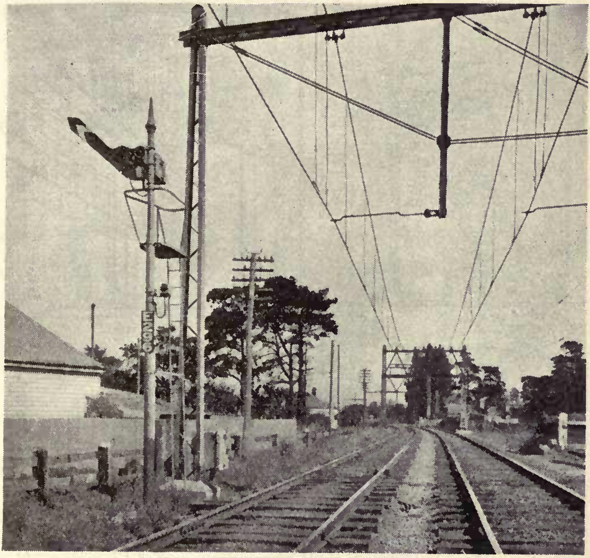


FIG. 56.—THREE-POSITION SIGNAL ON MAST WITH MARKER LAMP. (*Victorian Railways.*)

in Fig. 58 when the arm on S20 is at "danger." The instantaneous directions of the current are shown, and the circuit can be traced to the three-position signal relay at S30, resulting in the relay contacts being moved in the down direction, thus closing the local circuit to the 45 deg. position.

When the arm on S20 is in either the 45 or 90 deg. position, the pole-changer reverses the current (as seen in Fig. 59), moving the signal relay contacts in an upward direction and closing the local circuit to the 90 deg. position.

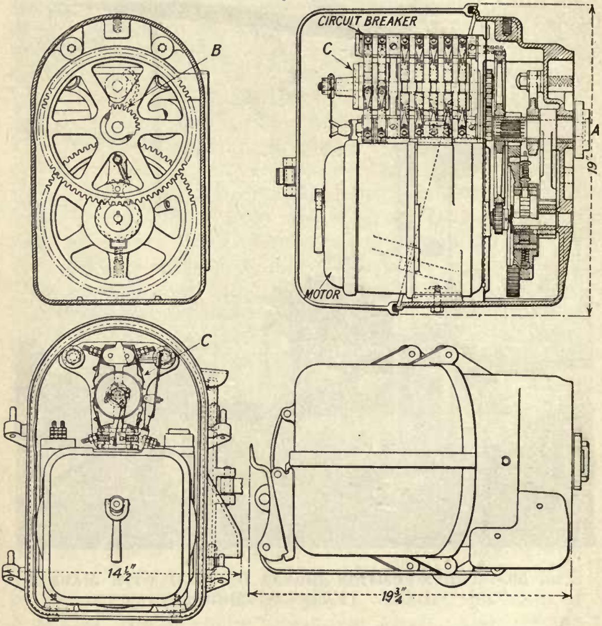


FIG. 57.—DETAILS OF THREE-POSITION SIGNAL MECHANISM.

In Fig. 60 is shown the circuit to the pole-changer, the relative polarities of the wires going to the signal changing with the position of the arm. This diagram also shows the 45 and 90 deg. control wires passing through contact fingers and segments on the circuit

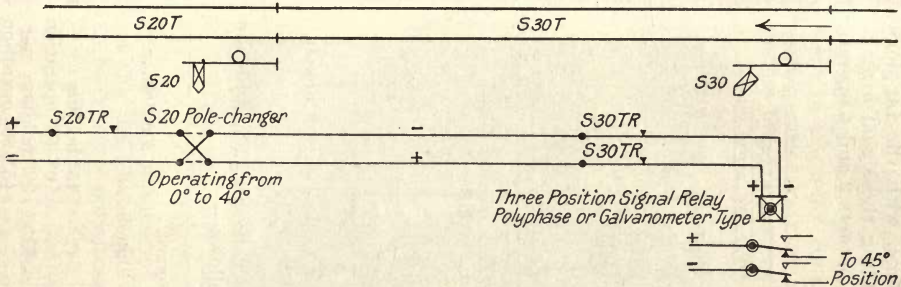


FIG. 58.—DIRECTION OF CURRENT WHEN THREE-POSITION SIGNAL ARM IS AT "DANGER."

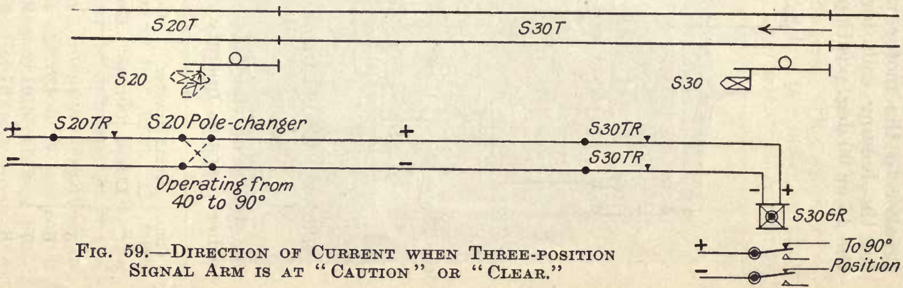


FIG. 59.—DIRECTION OF CURRENT WHEN THREE-POSITION SIGNAL ARM IS AT "CAUTION" OR "CLEAR."

breaker to the motor windings, with the tappings for the holding coils for holding the signal arm in the 45 or 90 deg. position. Contacts 2 and 4 operate

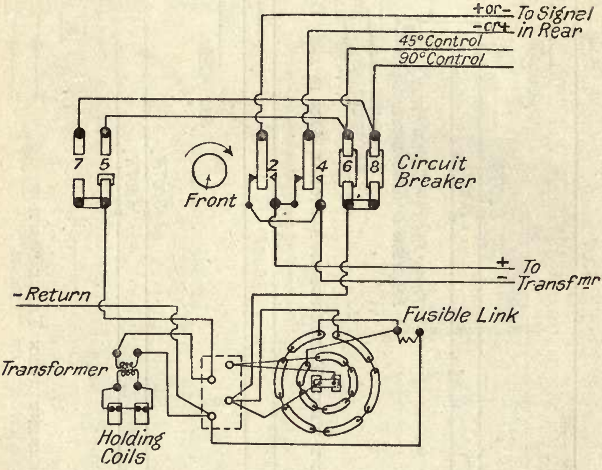


FIG. 60.—WIRING DIAGRAM FOR THREE-POSITION SIGNAL MECHANISM.

as shown at the pole-changer in Fig. 58, and the other contacts operate as follows—

Contact No.	Going Reverse.		Going Normal.		Function.
	Closes.	Opens.	Closes.	Opens.	
5	42°	46°	46°	42°	45° holding
6	—	43°	43°	—	0°–45° operation
7	87°	91°	91°	87°	90° holding
8	—	87°	87°	—	45°–90° operation

As stated in Chapter III, it is possible to create fields in the stator windings of the polyphase and galvanometer relays to result in giving three positions of the relay contact fingers. The shape of a three-position galvanometer relay is similar to that of the two-position relay; the armature windings

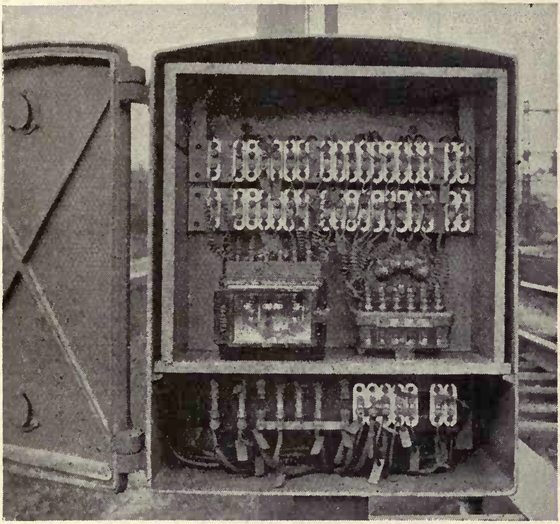


FIG. 61.—CAST IRON BOX FOR TWO RELAYS.
(*Victorian Railways.*)

consist of a number of turns of fine wire. As seen on the right-hand side of the case in Fig. 61, the three-position polyphase relay is different in shape from the two-position relay, but (as described in Chapter III) the method of operation is the same. The relay shown is fitted with two independent back and front contacts and four dependent front and back contacts; the method of connection from relay

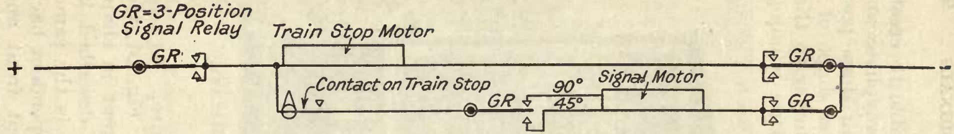


FIG. 62.—CONTROL CIRCUIT FOR THREE-POSITION SIGNAL AND TRAIN STOP.

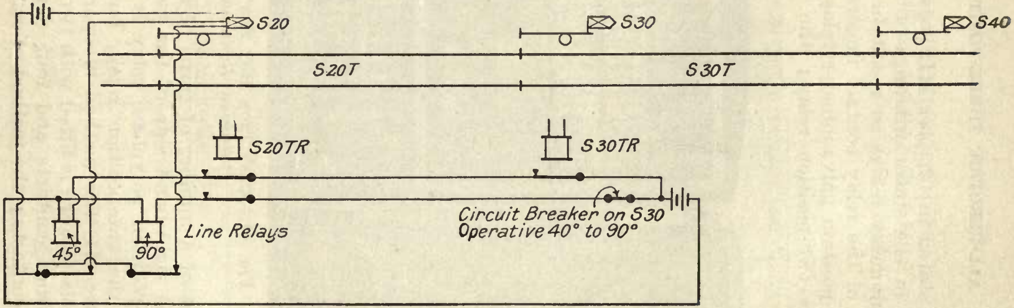


FIG. 63.—THREE-POSITION SIGNAL CIRCUIT USING 45° AND 90° RELAYS.

contacts to signal mechanism is shown in Fig. 62. It is the usual practice to house the track and signal relays in one case when the two are close together; but, when only one relay is required, a one-way relay box is used. These boxes may be made of cast-iron, cast-iron and sheet steel, or wood; a cast-iron box is shown in Fig. 61, with the polyphase track relay on the left and the signal relay on the right. Terminals fitted on to wooden panels are arranged above the relays, and are connected to the relay terminals by insulated flexible copper wires. Underneath the relays is the 110 V positive and negative distribution. As will be seen, each wire is labelled, and this lends itself to easy identification for tracing wires, as each connection has a wire number.

When three-position relays are not used for three-position signalling, it is necessary to use two relays: one controlling the 45 deg. position and the other the 90 deg. position. One method by which this can be done is shown in Fig. 63.

Fig. 64 shows a three-position upper quadrant electrically-operated signal actuated from a signal-box, and controlling the movements into the Ealing terminus of the Ealing and Shepherd's Bush Railway. The lower arms are "calling-on" signals. It was fixed by the Westinghouse Brake and Saxby Signal Co., Ltd.

Train-stop Mechanism. The necessity for providing this apparatus is mentioned briefly in Chapter I. There are many devices invented to give such a service, but few have been found to meet the severe tests imposed. The two methods usually adopted are: *either* (1) to fix the train-stop in the track, and the train-cock apparatus near the front wheels of the engine or coach; *or* (2) to fix the train apparatus on the roof, and the stop arm on the signal post. In the latter case, the automatic stop arm may be connected to the spectacle casting; and when the signal arm is in the "danger"

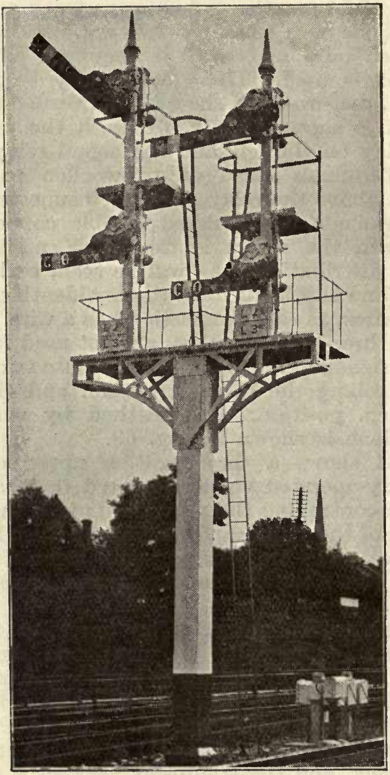


Fig. 64.—Three-position Upper Quadrant Signals.
(*Ealing and Shepherd's Bush Railway.*)

position, the stop arm is in position to engage with the arm of a valve located on the roof of an electric car. Should the train pass a signal in the " danger " position, the valve on the first car is tripped and automatically makes an emergency application of

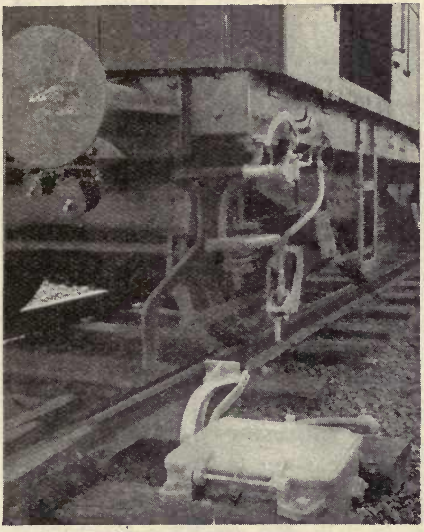


FIG. 65.—TRAIN STOP WITH TRAIN EQUIPMENT.
(*Victorian Railways.*)

the air, thus stopping the train. When the signal arm is at " clear," the stop arm is raised clear of the valve arm. Apparatus of type (2) has been fixed on the Anglo-Argentine Subway, Buenos Aires and on the Berlin Hochbahn.

On the lines using automatic train-stop apparatus in England, the apparatus is fixed on the track. The mechanism, in many cases, follows the same method of operation as the signal mechanism, i.e. a motor is provided to actuate the stop arm, and a holding-clear device is introduced.

In Fig. 65 is shown a train stop in use on the Victorian Railways which has two interesting features. The arm was made of sufficient strength to withstand, without distortion or injury, impacts from bodies

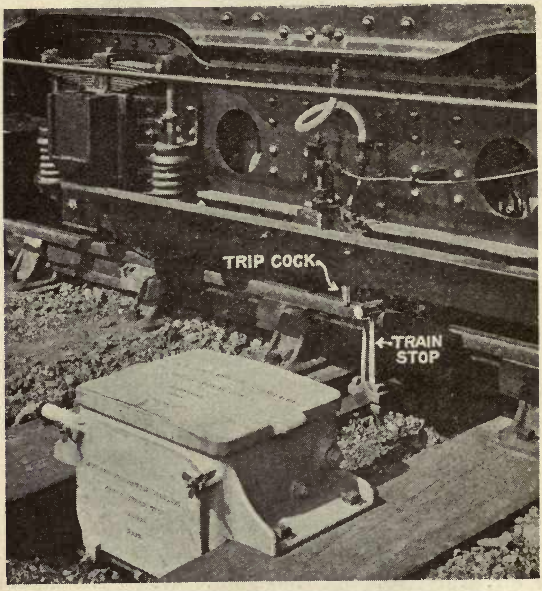


FIG. 66.—ELECTRICALLY-OPERATED TRAIN STOP. (*Ealing and Shepherd's Bush Railway.*)

weighing up to 4 lb. pivoted approximately 4 in. above the centre of gravity, and moving at 60 m.p.h. This was not an easy matter to attain, but was accomplished by the makers, the General Railway Signal Co., of Rochester, N.Y. When the stop mechanism is de-energized, the arm is raised 4 in.

above the top of rail and, when energized, the arm is $\frac{3}{16}$ in. to $\frac{1}{4}$ in. below the top of rail. The illustration also shows the trip-cock equipment fitted on an electric train.

The other feature is the provision of a special circuit breaker operated by the train-stop arm. This can be seen attached to the end of the trip-arm in Fig. 65, and its use is shown in the circuit diagram (Fig. 62), where the tap is taken from the train-stop motor feed through the train-stop contact. The idea of arranging the operation this way is to provide an absolute indication that the train-stop arm is in good order, as, should the arm be broken, the circuit breaker could not operate and the signal would remain at "danger."

Fig. 66 is an electrically-operated train stop installed by the Westinghouse Brake and Saxby Signal Co., Ltd., on the Ealing and Shepherd's Bush Railway.

Speed Signalling. In Fig. 67 will be seen aspects giving indications for two-arm, three-position automatic signals. This system has been developed on the Victorian Railways to make possible a close headway of suburban trains combined with main line expresses and goods trains at longer intervals. The normal speed varies from 40 to 52 m.p.h. according to the section, and the medium speed is 25 m.p.h.

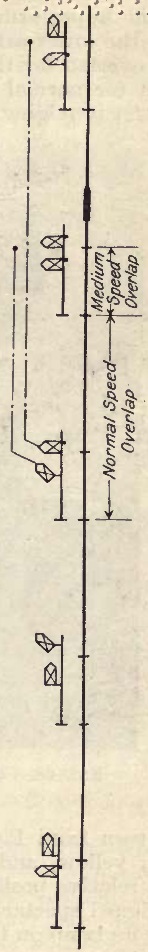


Fig. 67.—Controls for Automatic Speed Signalling.

The upper arm indicates normal speed signalling, and the lower arm, medium speed signalling. Thus the overlap for the medium speed can be made less than for normal speed, and advantage is taken of this for providing a closer headway of trains. As will

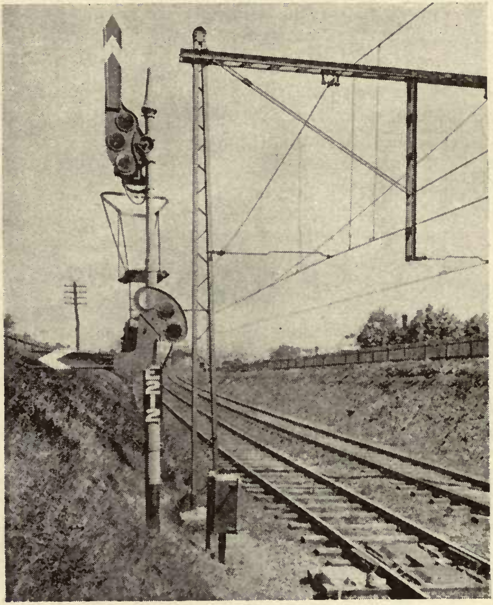


FIG. 68.—TWO-ARM THREE-POSITION SIGNAL.
(*Victorian Railways.*)

be seen from Fig. 52 (p. 81), the colours used are red, yellow, and green; and in order to preserve the relative position of the marker light, a specially designed spectacle is used for the upper arm, which has its lamp on the left of the post shown in Fig. 68.

CHAPTER X

LIGHT SIGNALS

Two types of this signal are used: the colour-light signal giving either two or three indications; and the position or beam-light signal which was invented by Mr. A. H. Rudd, Signal Engineer of the Pennsylvania Railroad, and Dr. W. Churchill, of the Corning Glass Works.

Lenses and Lamps for Colour-light Signals. As light signals must be discernible in broad daylight, when the sun is low and its rays are showing directly in the face of the lens, and with unfavourable background conditions, it is necessary to use either a high wattage lamp, or a lower wattage lamp with a concentrated and accurately-located filament. A good deal depends upon the employment of lamp and lenses of the highest possible efficiency, and many experiments and tests have been made to attain perfection. The tungsten filament lamp is more economical and satisfactory than the carbon lamp, the number of watts required per candle power being about three times greater with the carbon lamp. To obtain the greatest efficiency, it is necessary to concentrate the source of light in the smallest possible space, as close as possible to the focus of the lens or reflector; but it is not practicable to concentrate all the light at a point, and it is not desirable to reduce the spread of the projected beam too much. Lamp manufacturers have developed a concentrated filament lamp by winding the tungsten filament in a fine helical coil and looping this coil over the filament supports.

In order that the lamp bulb may be adjusted and focused correctly, it is usual to provide a focusing base for the lamps, so as to bring the filament right to the focus when new lamps are put in. As the sighting of the signal in daylight is more difficult than at night, the voltage for the lamps in some cases is raised during the daylight hours and reduced when it is dark. The average range of the red and yellow lights for this type of signal is about 2,000 ft., and of the green light, 1,500 ft. In some cases, however, these distances have been increased to between 3,000 to 3,500 ft.

Corrugated lenses, 8½ in. diam., are usually employed for the lamp cases, as having a more uniform cross-section than other types of lenses, this factor being necessary when coloured glass is used, otherwise the centre of the lens will be darker than the periphery.

A suitable hood, painted black, is sometimes fitted over the signal to eliminate the sun's reflection ; and an artificial background, made of sheet iron and painted black, is provided to bring the signal indication into good relief against the sky background.

Advantages of Light Signals. Before describing the several types of light signals in detail, the principal advantages of light signals over mechanism signals may be cited—

(i) There being no moving parts involved, the possibility of failure is reduced to a minimum and, when such a failure occurs, it involves only the replacing of a lamp bulb. Cost and time of maintenance are reduced, as it is only required to keep the lenses clean, and the lamp bulbs only require to be renewed at long intervals. The frequent re-painting required by semaphore signal arms is eliminated.

(ii) Light signal aspects have greater visibility and range under adverse weather and background conditions. A uniform indication is given at all times, night and day.

(iii) Coloured light signals can be used in places where the clearance would not permit either a position-light or a semaphore-mechanism signal to be used.

(iv) Power consumption is constant, but is slightly higher for beam-light signals than when using mechanism signals.

(v) Quicker operation of signal. A light-signal changes its indication almost instantaneously, whereas a signal mechanism requires several seconds to

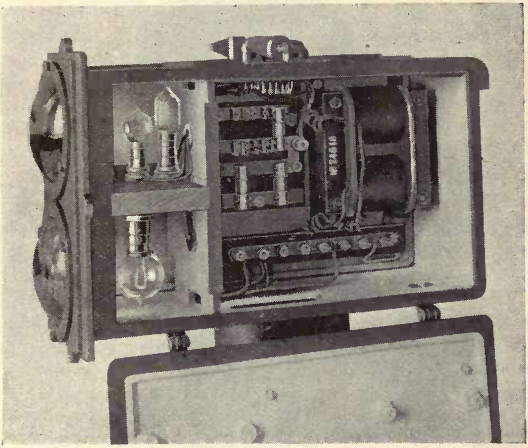


FIG. 69.—A.C. TWO-POSITION, TUNNEL TYPE, COLOUR-LIGHT SIGNAL.

operate. This is particularly noticeable when a signal changes from 0 to 90 deg., the light signal showing to great advantage.

(vi) The beam-light signal eliminates the use of various coloured lights for night indications and also, by the elimination of colours for signalling, the difficulties of colour blindness of the running staff are somewhat relieved. White lights can be seen more easily than coloured lights during foggy weather.

Two-position Colour-light Signals. Fig. 69 shows an a.c. two-position light signal used in tunnels, and manufactured by the Westinghouse Brake and Saxby Signal Co., Ltd. This compact signal is constructed of cast iron and, fitted inside the case, is the relay actuating the signal lamps. One lamp is placed behind each 4-in. lens. The lenses are coloured

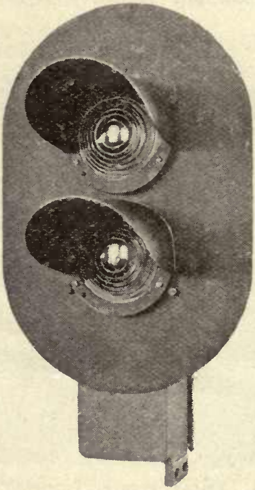


FIG. 70.—A.C. LONG-RANGE TWO-POSITION COLOUR-LIGHT SIGNALS.

either red and green, or yellow and green ; the green lens being the lower light.

This lamp is interesting on account of the use of a flux neutralizer fixed in the compartment behind the lamp bulbs. One winding of the flux neutralizer is connected in parallel with the lamps for the " danger " indication, the high inductance allowing very little current to flow through this winding when the signal is at " danger." The lamps for the " clear " indication are connected in series with the other winding of the flux neutralizer. When the line relay is energized, the full pressure of current flows through the green, or " clear," lamps and the flux neutralizer, thus establishing in the core of the flux neutralizer a magnetomotive force which neutralizes the flux in the winding which is in parallel with the " danger " lamps. This results in the latter winding losing its inductance, and so short-circuits the " danger " indication lamp, the light from which is thus extinguished when the green light is displayed. Each flux neutralizer is provided with a resistance to prevent excessive flow of current during the time the red-light circuit is short-circuited.

In July, 1921, there was brought into use the largest installation of daylight colour signals outside the United States. This was on the Liverpool Overhead Railway, where fifty-two of these signals (Fig. 70) were provided by the Westinghouse Brake and Saxby Signal Co., Ltd.

Experience, since they were brought into use, has proved two things: (1) The brightest sunshine does not impair the running view; and (2) the lights are better seen in fog than the lights of the usual semaphore signals. As to (1), it may be observed that the writer of the article in *The Engineer* of 11th November, 1921, descriptive of these signals, said that the day on which he inspected them was one of the typically fine days of the summer of 1921, but he was able to see the signals for 3,000 ft.

Whilst these pages were going through the press there was issued the report of a departmental committee appointed by the Ministry of Transport to investigate the potentialities of light signals. The committee saw the signals on the Liverpool Overhead Railway, and expressed the opinion that colour-light signals were better than the position-light signals (Fig. 75 p. 110). The report was very favourable towards colour-light signals, and went as far as to say " this type of signal could be arranged to meet, as far as can be seen, all conditions now covered by the existing semaphore type."

Three-position Colour-light Signals. Three-position colour-light signals may be made either in vertical or

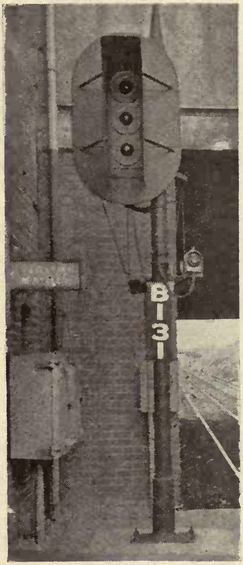


FIG. 71.—VERTICAL THREE-POSITION COLOUR-LIGHT SIGNAL.
(*Victorian Railways.*)

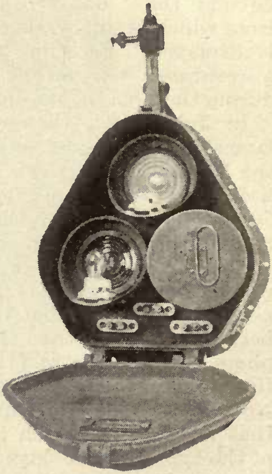


FIG. 72.—TRIANGULAR THREE-POSITION COLOUR-LIGHT SIGNAL.
(*Victorian Railways.*)

triangular units as shown in Figs. 71 and 72. In Fig. 71, the signal is shown mounted on a signal mast, and is fitted with background and hood. The bottom light is red, the centre light yellow, and the top light green. In the triangular type, the top light is green, the left bottom light is yellow, and the

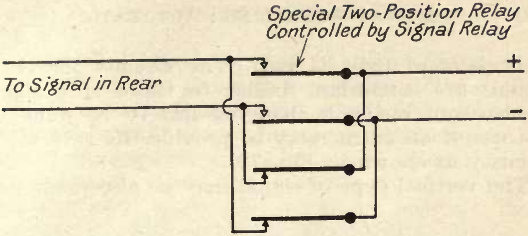


FIG. 73.—CIRCUIT FOR LIGHT SIGNAL IN PLACE OF MECHANICAL POLE CHANGER.

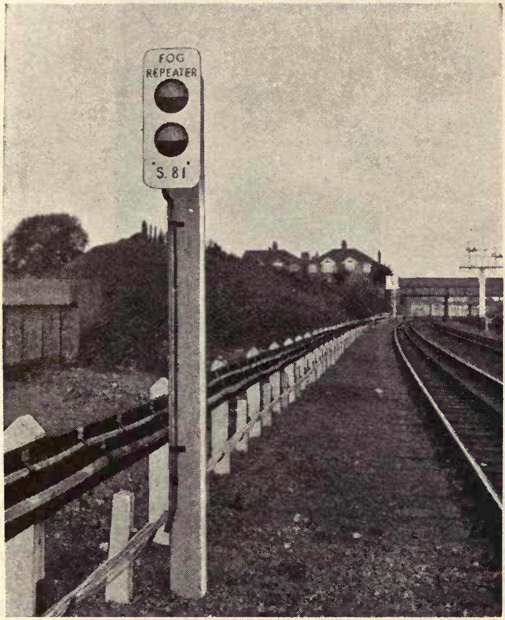


FIG. 74.—FOG REPEATER LIGHT SIGNAL.

right bottom light is red. The circuits for these signals are somewhat similar to those of a signal mechanism, but pole-changing has to be done by the use of an extra relay to provide the reversal of polarity as shown in Fig. 73.

The vertical type of signal may be also made into

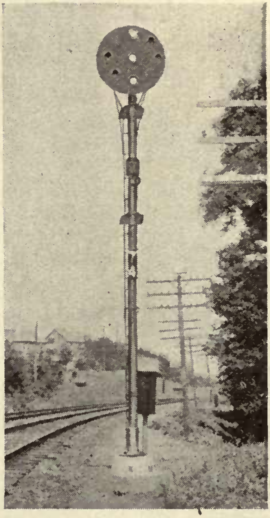


FIG. 75.—POSITION-LIGHT SIGNAL. (*Pennsylvania Railroad.*)

a two-position signal, fitted with hood and background.

Fog Repeater Signals. The underground railways of London have dispensed with the use of fog-signalmen. They provide, instead, the electrically-operated light signal (Fig. 74). This is fixed 100 yds. in the rear of the signal it repeats—in this case the signal on the left near the bridge in the distance—and the lamps are about on a level with the motorman's eyes.

The upper lens gives a yellow light and the lower a green. When the signal it repeats is at " danger " or " caution," the yellow light is switched in ; when the signal is at " clear," the green light is given.

The fog repeaters are only in use when there is fog, and each signal-box switches in those in its neighbourhood when the necessity arises. They were first introduced by the Metropolitan Railway, and are made by the Westinghouse Brake and Saxby Signal Co., Ltd.

Position-light Signals. The Pennsylvania Railroad has fixed a large number of position-light signals (Fig. 75), in which the indications of a three-position signal are given by rows of white lights. There are nine white lights altogether, but only one row of three lamps can be alight at the same time. The horizontal row signifies " danger " ; an inclined row indicates " caution " ; and the vertical row, as seen in the illustration, gives " clear."

Whilst this type of signal has its advantages—the main one being that the colour question is eliminated—there are several directions in which the colour-light has a superiority.

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AUTOMATIC railway signalling has to be provided under so many different circumstances, that a comprehensive survey of the subject would necessitate the writing of many volumes. As each installation shows an improvement on earlier arrangements, it is necessary to follow the latest practice by reading the periodical literature devoted, or giving space, to signalling matters. The *Railway Gazette* and the *Railway Engineer* are constantly having illustrated articles on signalling practice ; and the *Railway Signal Engineer* (Chicago) is devoted entirely to signalling matters.

The Institution of Railway Signal Engineers, London, and the Signal Section of the American Railway Association, New York, are composed of those interested in signalling ; and papers on different subjects in signal engineering are read and discussed. At intervals, papers on signalling are read at the Institutions of Civil Engineers, Electrical Engineers, and Mechanical Engineers, extracts of which are usually given in the technical press. The Signal Section of the A.R.A. publishes a manual, which contains standard specifications and drawings for signal engineers and the signal manufacturing firms. Under these circumstances, it is customary to find more standard arrangements with automatic signalling than has been the practice with mechanical signalling.

The amount of literature on automatic railway-signalling is small, but, what little there is, is good. By studying the books mentioned below and by following the latest practice in the periodical papers mentioned above, a very good idea of modern arrangements may be obtained.

Power Railway Signalling, by H. Raynar Wilson, published by the St. Margaret's Technical Press, 33 Tothill Street, S.W.1.

Modern Developments in Railway Signalling, by E. A. Tattersall published by the Railway Engineer, 33 Tothill Street, S.W.1.

Electric Interlocking Handbook, published by the General Railway Signal Co., Rochester, New York.

Alternating Current Signalling, published by the Union Switch and Signal Co., Swissvale, Pennsylvania.

Proceedings of the Institution of Railway Signal Engineers: M. G. Tweedie, 82 Caversham Road, Reading, Hon. Sec.

The undermentioned Technical Primers, uniform with this volume (Pitman, 2s. 6d. net), are likely to interest readers of this book—

Railway Signalling: Mechanical, by Fras. Raynar Wilson.
Electrical Insulation, by W. S. Flight. (In preparation.)
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